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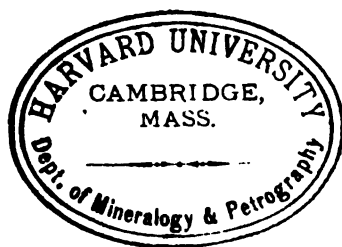
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UNITED STATES

GEOLOGICAL SURVEY

No. 157



WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

THE
GNEISSES, GABBRO-SCHISTS, AND ASSOCIATED ROCKS
OF
SOUTHWESTERN MINNESOTA

BY
CHRISTOPHER WEBBER HALL



WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

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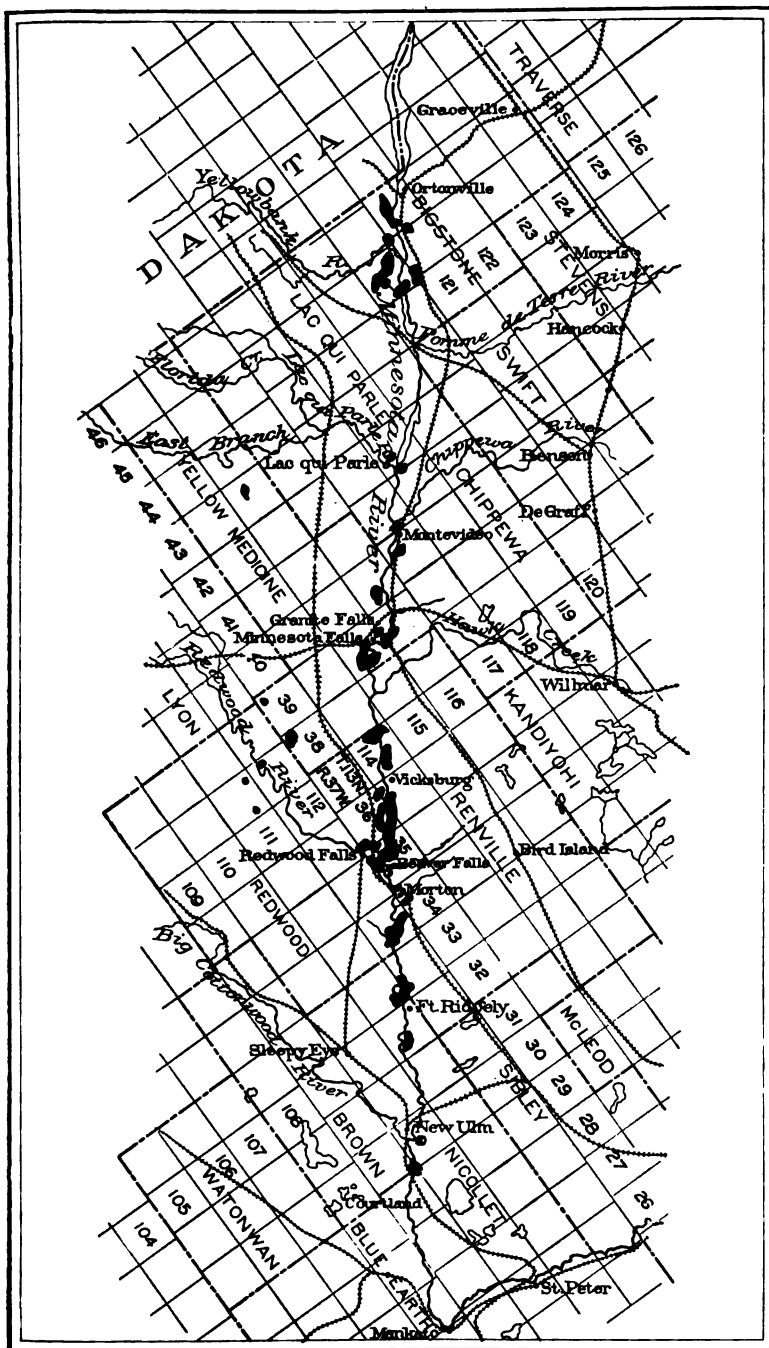
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MAP OF A PORTION OF SOUTHWESTERN MINNESOTA, SHOWING OUTCROPS
OF CRYSTALLINE ROCKS.

THE GNEISSES, GABBRO - SCHISTS, AND ASSOCIATED ROCKS OF SOUTHWESTERN MINNESOTA.

By O. W. HALL.

CHAPTER I.

INTRODUCTION.

The territory from which the material for this paper was gathered embraces that part of the Minnesota River Valley lying between Courtland and Ortonville and that portion of the State of Minnesota to the west and south of the river named wherever gneisses are found. (See Pl. I.) The area is about 5,500 square miles in extent.

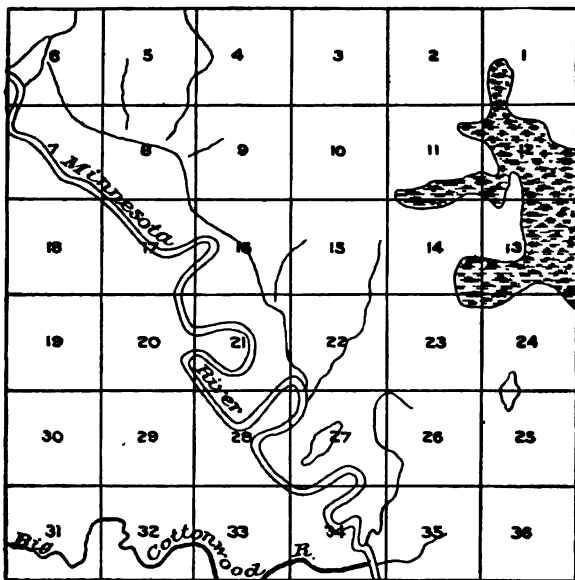


FIG. 1.—A township from the United States Government survey—T. 110 N., R. 30 W., Minnesota.

This entire area has been platted by the land surveyors of the Government, and geologists are thus enabled to locate accurately every sample gathered. Wherever in the following pages a definite location is given, the township and range are named, and the paces, on the basis of 2,000 to the mile, north and west from the southeast corner of

the section are stated. Occasionally, however, it was found that the surveyors' monuments and section posts had disappeared, and then the distances were estimated.

Although the area embraced in this study reaches well up to the headwaters of the Minnesota River, the rock elevations do not attain great heights above the sea. Probably no outcrop occurs at a higher elevation than 1,200 feet. This portion of the State is deeply drift covered, and wherever the rocks appear above the present high-water mark of the Minnesota River they protrude in well-rounded knobs or bosses, sometimes of small size, and never of great extent, either in height or in area. As a consequence of the heavy drift covering, we find few outcrops upon the prairie beyond the morainic bluffs which bound an ancient flood plain of the Minnesota River. These few are

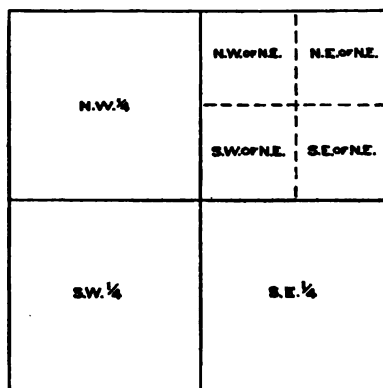


FIG. 2.—A section 1 mile square. One mile = 2,000 paces.

the highest masses of an eroded rock surface protruding through the glacial drift.

The flood plain of the Minnesota River is from 1 to 5 miles wide throughout its course from Ortonville to and beyond New Ulm, and was formed while the valley was a channel of outflow from Glacial Lake Agassiz, extending northward through the present Red River Valley. Projecting through this flood plain are many exposures of gneisses, gabbro-schists, diorites, and diabasic effusives. In the 120 miles between Ortonville and New Ulm the rocks named "often fill the entire valley, 1 to 2 miles wide, rising in a profusion of knobs and hills 50 to 100 feet above the river."¹

Unless there be assumed a considerable elevation of the central portion of the continent, it must be supposed that during Glacial or pre-Glacial time the descent of the River Warren was a gentle one. Such is that of its successor, the Minnesota River, of post-Glacial time. This fact, and the presence, throughout the upper portion of its course,

¹ The Minnesota Valley in the Ice age, by Warren Upham: Proc. Am. Assoc. Adv. Sci., 1883, p. 215.

of crystalline rocks, have determined the slight depth below the Warren flood plain to which the bed of the river has been eroded. Few rapids occur, and these are where the river crosses the strike of the gneisses. The Minnesota River at Courtland stands 807 feet above the Gulf of Mexico, and the elevation of Bigstone Lake, a widening of the river near Ortonville, is 962 feet.

The few exposures occurring outside this ancient river valley lie in the towns of Omro, Posen, Echo, Vesta, Johnsonville, and Vaill, south and west of the Minnesota River. The next exposures in these directions beyond the townships named are the glaciated knobs of red quartzite in Cottonwood and Watonwan counties, and other quartzite exposures among the Coteau des Prairies—called Shining Mountains¹ by the early explorers of the Northwest—in Rock and Pipestone counties, from which, with many a superstitious ceremony, the Indian quarried the soft catlinite for his pipes.

North and east of the Minnesota River the Leaf Hills and the uniformly thick beds of till cut off the Minnesota River Valley series of gneisses and associated rocks from the granites and schists of the Mississippi Valley, whose most southwesterly exposures, so far as known, lie in Stearns County.²

In locating the geological boundaries of the Minnesota River formations, as has been done on the accompanying maps, sometimes an approximation only is possible. Wherever the drift covering conceals the underlying rocks the rock boundaries are denoted by dotted lines.

¹Travels through the Interior Parts of North America in the Years 1766, 1767, and 1768, by Jonathan Carver, Dublin, 1779, p. 46.

²Preliminary report on the geology of central and western Minnesota, by Warren Upham: Eighth Ann. Rept. Geol. Nat. Hist. Survey Minnesota, p. 75; and also The geology of Ottertail County, by Warren Upham: Final Rept. Geol. Nat. Hist. Survey Minnesota, Vol. II, p. 546.

CHAPTER II.

SUMMARY OF EARLIER OBSERVATIONS.

In the mass of material published by the earlier explorers and the later scientific investigators who have given their attention to the northwestern Territories and States, little reference is made to the rocks which form the subject of the present study. For the purpose of historic and scientific reference the following list of titles and abstracts is made. The order is chronological.

SEPARATE PUBLICATIONS.

1. CARVER (Jonathan). *Travels through the interior parts of North America in the years 1766, 1767, and 1768.* Dublin, 1779.

Carver wrote an exceedingly interesting book, but he said very little on the geology of the Northwest. The St. Peter (Lower Silurian) sandstone is briefly mentioned, not by that name but as a snow-white rock crumbled outwardly by the wind and weather. The crystalline rocks farther up the Minnesota River Valley are not alluded to.

2. KEATING (William H.). *Narrative of an expedition to the sources of the St. Peter's River, Lake Winnepeek, Lake of the Woods, etc., performed in the year 1823, " " " under the command of Stephen H. Long, U. S. T. E.* London, 1825. 2 vols.

Professor Keating, of the University of Pennsylvania, geologist and historiographer of Major Long's expedition, indulged in many philosophical reflections on the character and constitution of the granitic rocks met with in the explorations of the party with which he was connected (Vol. I, pp. 362-382, and elsewhere). In the primitive rocks above Redwood Falls it seemed to Keating "as if four simple minerals, quartz, feldspar, mica, and amphibole, had united here to produce almost all the varieties of combinations which can arise from the association of two or more of these minerals, and these combinations were in such immediate contact that the same fragment might, as we viewed one or the other end of it, be referred to different rocks; while in some places granite was seen perfectly well characterized; in others a gneiss, mica-slate, greisen (quartz and mica), compact feldspar (Weisstein of Werner), syenite, greenstone, and the syenite with addition of quartz, forming the amphibolic granite of D'Aubuisson, were equally well characterized. The only rock composed of these principles which we did not observe,

but which may perhaps exist there, is the graphic granite (pegmatite, Haüy)." (P. 365.)

Keating also advances the suggestion that the Coteau des Prairies, as the dividing ridge between the waters of the Mississippi and those of the Missouri, "is doubtless the grand dike which has obstructed the latter in its progress eastward and caused it to flow southwardly through a distance of many hundred miles, before it could again resume a direct course to the former." (Vol. II, p. 220.)

3. BELTRAMI (G. C.), esq., formerly judge of a royal court in the ex-kingdom of Italy. A pilgrimage in Europe and America, leading to the discovery of the sources of the Mississippi and Bloody river, with a description of the whole course of the former and of the Ohio. Printed for Hunt and Clark. London, 1828. 2 vols.

Beltrami several times alludes to the rocks of the Minnesota River Valley. Those at the Redwood River he speaks of as granite of a beautiful and varied quality. It is not necessary to make here any quotation from Beltrami's work.

4. FEATHERSTONHAUGH (G. W.), U. S. geologist. Report of a geological reconnaissance made in 1835, from the seat of government, by the way of Green Bay and the Wisconsin Territory to the Coteau de Prairie. Document 333. Printed by order of the Senate. Washington, 1836.

Featherstonhaugh mentions gneiss at the Grand Portage (Granite Falls), east of Lac qui Parle, as dipping southeast, with an almost vertical inclination (introduction). He further says concerning this rock that it has "little or no mica" (p. 28), and that it "resembles granite in every particular except its stratification" (p. 149). Granite, he says, was of frequent occurrence, and was the only rock seen in places beyond the mouth of the Waraju (Cottonwood) River toward the northwest, the last seen described as consisting of "immense masses of granite in place, isolated from each other, and occupying several hundred acres. Some of these masses are 25 feet high; they extend 6 or 8 miles down the valley and give its name of Eatatenka or Great Rocks to the lake [Bigstone Lake]." (P. 157.)

In a later publication¹ the same author mentions many localities between Redstone (Courtland) and Bigstone Lake, where granites occur, and many details concerning them are given.

5. NICOLLET (J. N.). Report intended to illustrate a map of the hydrographical basin of the Upper Mississippi River. Senate Doc. 237, 2d sess., 26th Congress, February 16, 1841.

The valley of the Minnesota River, together with other tributaries of the Mississippi, is mapped. The general trend of the Minnesota River and the situation of its branches are portrayed with remarkable accuracy, considering the fact that there were no primary surveys at that time to give guidance to the work.

¹ See No. 6, following page, Vol. I, Chapters XXVIII to XXXV.

6. FEATHERSTONHAUGH (G. W.). *A canoe voyage up the Minnay Sotor*. London, 1847. 2 vols.

The geological observations of Featherstonhaugh in this expedition have already been referred to. He saw many bowlders of the primitive rocks, from escarpments of vertical granite and rugged granite hills "resembling parts of Dartmoor." (Vol. I, p. 325.) Elsewhere he saw "immense masses of granite all quasi-stratified, in laminae about an inch broad." (Ibid., p. 333.)

7. ALLEN (Lieut. J.). *Map and journal of, in charge of escort accompanying Schoolcraft's expedition to the sources of the Mississippi*. American state papers, documents, legislative and executive, of the Congress of the United States from the first session of the Twenty-fourth Congress inclusive, Vol. V., Military Affairs, pp. 312-344.

Lieutenant Allen, in this rather detailed report, published a map of the region now embraced in southwestern Minnesota, which was compiled with great care from the information then at hand. The chains of hills and mountains as located on the map show the explorers' and author's views of the situation and trend of the geological formations, which have had so marked an effect on the topography of the region.

8. OWEN (David Dale), U. S. geologist. *Report of a geological survey of Wisconsin, Iowa, and Minnesota; and incidentally of a portion of Nebraska Territory*. Philadelphia, 1852.

With the advent of Owen into the Northwest we enter the time of more active and systematic research. This geologist, with his chief assistant, Dr. Norwood, and such aids as Shumard and Whittlesey, came for the distinct purpose of throwing light on the geological character of the territory comprised within the field of operations, and of presenting such practical results as might be drawn therefrom by Government officers and prospective settlers.

Shumard began an examination of the St. Peter (Minnesota) River, but an attack of pleurisy at the Redwood River put a stop to his further progress. He located the boundary between the quartzite conglomerate and the granitic rocks of the valley nearly opposite New Ulm. "About 1 mile in a straight line above the mouth of the Waraju, and 3 miles by the course of the river, we found some outliers of coarse conglomerate and granite a short distance from the bank of the stream. The conglomerate is composed mainly of quartz pebbles and bowlders, some of the latter 10 inches in diameter; the whole cemented with a siliceous material. . . . The course of the exposure is nearly east and west, with a dip toward the south of 20°. . . . The granite is 100 yards removed from the conglomerate. . . . Flesh-colored feldspar forms nearly two-thirds of the granite." (P. 491.)

9. **WHELOCK (J. A.)**, commissioner of statistics. *Minnesota: its place among the States.* First annual report of the commissioner of statistics for the year ending January 1, 1860. Published by authority of law. Hartford, 1860.

Touching southeastern Minnesota, Wheelock says: "From the head of Lake Superior a narrow granitic spur of this primary rock, divested of the volcanic *débris* in which the mineral wealth of Lake Superior is embedded, stretches southwesterly under the drift, beyond the boundary of the State, revealed only when it crosses the Mississippi at Sauk Rapids, the Minnesota between the Cottonwood and the Redwood, and the Big Sioux at Sioux Falls. This granitic seam intervening in the sandstone has a breadth upon the streams which it crosses of from 40 to 50 miles" (p. 53).

10. **ANDERSON (Charles S.) and CLARK (Thomas).** Report on geology and plan for a geological survey of the State of Minnesota. Made in accordance with a concurrent resolution passed by the second legislature of Minnesota, March 10, 1860.

This report of Anderson and Clark merely alludes to "an extensive range of the primitive system of rocks" . . . which "appear on the Minnesota River about the mouth of the Redwood River. Although sometimes termed a mountain by geologists, the highest elevation of these ranges does not exceed 2,000 feet above tide water." The breadth of this granitic region is out of proportion to its elevation—considering it a mountain—being about 60 or 70 miles. . . . Here are also found nearly all varieties of the granitic and metamorphic rocks (p. 5 et seq.).

This report is of historic interest in that it marks the beginning of geological surveys by the State of Minnesota.

11. **HALL (James).** Notes upon the geology of some portions of Minnesota, etc. *Transactions of Philosophical Society*, Vol. XIII, N. S., Philadelphia, 1869.

Professor Hall, in speaking of an area about Courtland, says: "Then rises to the surface a reddish-brown crystalline rock having a granitoid aspect, but when critically examined is found to consist mainly of quartz and feldspar without the perceptible admixture of other minerals. . . . We have, therefore, an almost continuous exposure of the strata for more than 100 feet in thickness. There is a distinct dip to the northeast." (P. 330.) Further on he adds: "I conceive it to be sufficiently demonstrated that the quartzites at Redstone Ferry [Courtland] on the Minnesota River—those near the sources of the Little Cottonwood, . . . together with those of the escarpments of Pipestone, . . . are of the same age. These quartzites I regard as of the age of the Huronian formation of Canada and the quartzites of Wisconsin." (P. 338.) Turning now to the older rocks, Professor Hall says that around Redwood Falls they are gneissoid, and "in many places these rocks are intercalated by steatitic or glauconitic beds, and the entire mass is in a state of decomposition to the depth of 80 or 100

feet. It would be of much interest," he continues, "to ascertain the relation which the dip and direction of these older gneissoid rocks bear to the succeeding quartzites, which evidently belong to the Huronian system" (p. 335). (See fig. 3.)

12. CHAMBERLIN (T. C.) and assistants. *Geology of Wisconsin, survey of 1873-1879.* By the commissioners of public printing, Madison. 4 vols. Vol. II, 1877; Vol. III, 1880; Vol. IV, 1882; Vol. I, 1883.

In the discussion of the "quartzites of Barron and Chippewa counties, compiled from the notes of Messrs. Strong, Sweet, Brotherton, and Chamberlin," reference is made to the quartzites near New Ulm, Minnesota, and to the Sioux quartzites of Iowa. The equivalence of the quartzites of Barron and Chippewa counties to the Sioux and New Ulm quartzites is to be inferred by the reader. These southwesterly exposures, like those in Wisconsin, are regarded as outcropping marginal portions of a quartzite belt extending, with some possible interruptions, through three or four States. The lithological characters of the quartzites of the several areas enumerated and their relationship to the Laurentian and the Paleozoic formations sanction their reference to the Huronian age. (Vol. IV, pp. 575-581.)



FIG. 3.—Section from Courtland to Pipestone, Minnesota. (After James Hall.)

a. Quartzites east of the Minnesota, at Redstone Ferry, dipping eastward. b. The outcrop of quartzites near the source of the Little Cottonwood dipping to the westward. c. The outcrop of quartzites at the Pipestone locality, dipping to the eastward. d. The interval between a and b, made by an eroded anticline which is now occupied by Cretaceous and more recent formations along this line. (An east-west section 40 miles north of this point shows the continuity of the Cretaceous formation interrupted by numerous prominences of Laurentian gneiss.) e. The lower country west of the Pipestone locality occupied by modern formations similar to d. R. Minnesota River. R'. Sioux River. The space between the two upper lines is intended to represent prairie formation. f. The place of the Pipestone stratum.

13. WINCHELL (N. H.). *History of the Minnesota Valley.* Minneapolis, 1882.

Chapter XXIX is devoted to the geology of the Minnesota Valley. This chapter is practically an epitome of Professor Winchell's observations in the Minnesota Valley in 1873, published in detail in the annual report of the Geological and Natural History Survey of Minnesota for that year. This report will be referred to in another place.

14. WINCHELL (N. H.) and UPHAM (Warren). *The geology of Minnesota.* Minneapolis, Vol. I, 1884, and Vol. II, 1888. Vols. I and II of the final report.

Mr. Upham's descriptions and field notes of the geology of the Minnesota River Valley are numerous and valuable. Special reference is here made only to the following topics and pages: Decomposed gneiss and granite (of Brown and Redwood counties) (p. 570), Potsdam quartzite (p. 572), the Eozoic rocks of Yellow Medicine County (p. 596), granite and gneiss of Lac qui Parle and Bigstone counties (p. 617), all in Vol. I; Archean rocks of Renville County (p. 194), Archean rocks of Chippewa County (p. 210), in Vol. II.

Further citations from Mr. Upham's writings will be made where the particular topics he writes upon are discussed.

SERIAL PUBLICATIONS.

15. *Proceedings of the American Association for the Advancement of Science, Salem, Massachusetts, since 1848.*

In an extremely interesting description of the Minnesota Valley during the Ice age, Warren Upham maintains (Vol. XXXII, 1883, p. 215) the ancient crystalline character of the underlying rocks of the Minnesota River Valley in these words: "In the 100 miles from Bigstone Lake to Fort Ridgely the strata are metamorphic gneisses and granites, which often fill the entire valley, 1 to 2 miles wide, rising in a profusion of knobs and hills 50 to 100 feet above the river."

In 1884, at the Philadelphia meeting, N. H. Winchell delivered the vice-presidential address in Section E on The Crystalline Rocks of the Northwest. In the grouping and correlation of these rocks the author says that "the outcrop of red granite near New Ulm, lying under the conglomerate and red quartzite, is probably the southwestward extension of 'the gabbro and red syenite at Duluth.'" These he calls the first group, i. e., the uppermost series of the crystalline rocks of the Northwest. (Vol. XXXIII, p. 364.) He further adds: "This group is represented by No. XX southwest of Lake Michigamme [in the upper peninsula of Michigan], by No. XX at Menominee [in Michigan and Wisconsin], and by Nos. 1 and 1a at Black River [in Wisconsin]."

16. *Reports of the Chief of Engineers, U. S. Army, Washington, since 1866.*

In the records of the work of the Corps of Engineers, United States Army, between 1867 and 1879, many facts of geological interest are stated and discussed. No engineer of the Army stationed of late years in the Northwest has taken a deeper interest in geologic and physiographic studies than Gen. G. K. Warren, after whom, "in honor and in memoriam," the River Warren has been named.¹ No one can fail to find profit in studying, from a geological standpoint, what General Warren has set forth regarding the physical features of the Mississippi and Minnesota river valleys and the history of their formation.

In his report for 1868 General Warren discussed the extensive erosion which the Upper Mississippi Valley has undergone, the evidences which this valley presents of a former elevation of the central part of the North American continent, and the almost entire lack of abrasion which the granite bed of the Minnesota River reveals in the upper part of its course (pp. 305-314). In 1873 a report was made of an "examination and survey of the Minnesota River above the mouth of the Yellow Medicine." The average fall of the stream, the character of the bluffs bordering it, and the location and extent of the lakes found along its course are given. The granite which occurs at the foot of

¹ Warren Upham, *Proc. Am. Assoc. Adv. Sci.*, Vol. XXXII, 1883, p. 231.

Bigstone Lake is designated feldspathic (pp. 438, 439). In 1875-76 a very detailed report on the Mississippi River was published (Vol. II, Part L, pp. 381-451), containing "An essay concerning important physical features exhibited in the valley . . . and upon their signification." This valuable paper is illustrated by several maps and charts.

In 1878 the mature results of General Warren's labors appeared in the report on bridging the Mississippi River, containing several maps and diagrams. These results bear on the glacial origin of the Minnesota Valley, the existence of a glacial river, subsequently named River Warren by Warren Upham, and the occurrence of silted lakes between Ortonville and Courtland. They will be frequently referred to in subsequent pages.

17. *The Minnesota Teacher*, St. Paul, 1867-1875.

W. D. Hurlburt, a gentleman who has observed the geology of the State as his business carried him to various places, stated in this publication (Vol. IV, 1871), that "a band of granitic rocks forms the bed of the river [at Redwood Falls] similar to the exposures at Sauk Rapids and above [on the Mississippi River], and these indicate at once the shore line of the Azoic continent and the northern border of nearly all the sedimentary rocks in place in Minnesota" (p. 5).

18. *The American Naturalist*, Salem, Philadelphia, and New York, since 1867.

In Vol. II, 1868, an article by Gen. G. K. Warren, entitled, *Certain Physical Features of the Upper Mississippi River*, is discussed. The great excavation of the Minnesota River above Fort Snelling is cited, and the fact is stated that the bed of this river "for 110 miles below Bigstone Lake is partially granitic" (p. 497).

Emphasis is laid on the proposition that "the waters issuing from a lake have little abrading power, for they have comparatively little rubbing material to operate with.¹ Thus it was that the waters issuing at the old southern outlet of Lake Winnipeg (Lake Agassiz of Warren Upham) could make no impression on the granitic bed of the Minnesota. Had the granite been soft, like the Silurian rocks lower down in its course or like the Tertiary and Cretaceous rocks through which the Missouri has cut its way, then this part of the valley would have been worn away in the same manner, and we should have the drainage of all the Winnipeg Basin still to the southward. A cut of 400 feet at Bigstone Lake would have drained it, and the banks would then not have been as high as those of the Missouri at the Bijou Hills, which are 800 feet above the water of the river" (p. 500).

19. *The Geological and Natural History Survey of Minnesota*, Annual Reports, Minneapolis, since 1872.

Under this survey (still in progress) N. H. Winchell, State geologist, inspected the valley in 1873. The granites were held to be of a pre-

¹ Compare *Geology of the Henry Mountains*, by G. K. Gilbert, Washington, 1880, paragraph on Corrasion, p. 101.

vailing reddish color. That they are "schistose granites" is emphasized. The granite at La Framboise's place, described as a "type," is made up of the "ternary granite compound." The tendency to decompose into an impure kaolin, seen at Birch Cooley and Redwood Falls, is also mentioned. Since this material, provisionally called kaolin, prevails in the Cretaceous areas and is always present, so far as known, wherever the Cretaceous deposits have preserved it from disruption by the ice erosion of the Glacial period, its origin may be attributed to the action of the Cretaceous ocean. (Report for 1873, p. 163.)

20. The Minnesota Academy of Natural Sciences, Bulletins, Minneapolis, since 1873.

In Vol. III, Bulletin No. 1, Warren Upham has described (p. 151) a set of "maps showing the climate, geography and geology of Minnesota." In outlining the distribution of rocks throughout the State he says that the rocks of southwestern Minnesota are "mainly red quartzites exposed near New Ulm and thence westward to Pipestone and Rock counties in the southwest corner of the State." The Archean system reaches from "the international boundary from the Lake of the Woods east to Lake Superior and extending thence southwest to the Minnesota River between Bigstone Lake and New Ulm, but terminating 20 or 30 miles southwest of this river" (p. 154).

21. Bulletins United States Geological Survey since 1883.

In Bulletin No. 8, on Secondary Enlargements of Mineral Fragments in Certain Rocks, R. D. Irving and U. R. Van Hise have discussed secondary enlargements of mineral fragments in certain vitreous quartzites (and sandstones) in the quartzite formation of southern Minnesota.

The similarity in character of these quartzites to the Huronian quartzites of the Baraboo district of Wisconsin, and to much of the quartzite of the Huronian of Lake Huron is pointed out. "At Redstone [Courtland] the transitions from argillaceous, reddish sandstone to completely vitrified, brick-red to purple quartzite, and from these again to completely loose sandstones, are frequent and abrupt." The fact is also emphasized that "over considerable areas the appearance is as if the rock at the higher levels had been vitrified by exposure." (P. 34.) Yet the appearance of the quartzite in the railway cuttings and elsewhere suggests the possibility that this vitrification may be due to the descent and spreading of a silica-bearing solution (p. 34).

22. The Geological and Natural History Survey of Minnesota, Bulletins, Minneapolis, since 1887.

23. The American Geologist, Minneapolis, since 1888.

CHAPTER III.

GEOGRAPHICAL DISTRIBUTION AND GENERAL CHARACTERS OF THE ROCKS OF THE MINNESOTA RIVER VALLEY.

Before proceeding to a detailed description of the crystalline rocks under discussion, a résumé of their geographical position will be given, and the general characters of these rocks, more especially with reference to their structural relations and peculiarities of texture, will be outlined.

In passing up the Minnesota River from its mouth at Fort Snelling to South Bend a southwesterly course is followed, the river flowing in a northeasterly direction. The river runs through a troughlike valley, whose walls, partly of Cambrian dolomite and sandstone and partly of glacial débris, reach a height of 200 to 250 feet. These walls are from 1 to 4 miles apart.¹ At South Bend a right angle is turned, to which the river comes down from the northwest. Near this point the volume of the stream is enlarged by the addition of streams of some size flowing in from the south. Along the banks of one of these streams, the Lesueur, the explorer of that name found deposits of copper ore, from which quantities were sent to France for assay in the year 1700. Continuing up the river, it is not until T. 109 N., R. 30 W. is entered that any crystalline rocks are found. This area of crystalline rock is called the Courtland district, from the township of that name.²

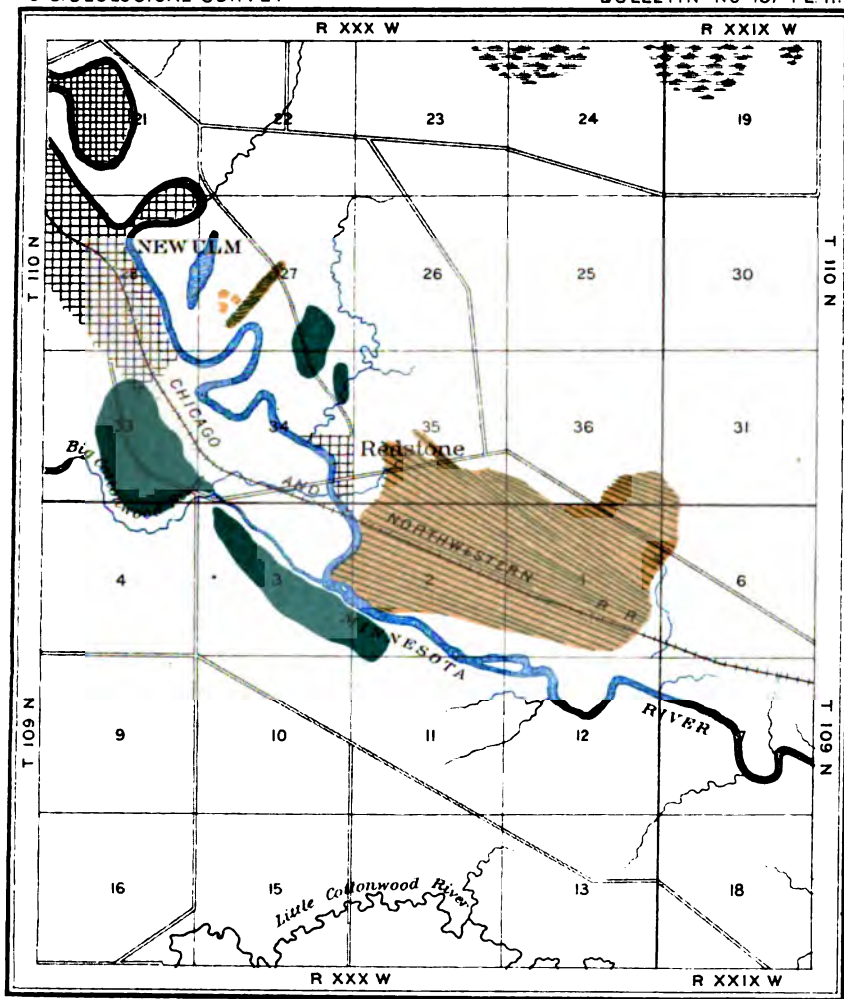
COURTLAND DISTRICT.

QUARTZITE EXPOSURES.

The pre-Cambrian rocks first found in passing up the Minnesota River Valley are red quartzites (see Pl. II) with associated quartzite conglomerates and sandstones. These exposures have been visited by nearly all the geologists and explorers who have traversed the Minnesota River Valley. The rocks are not continuously bare from the river to the summits, but lie exposed in a series of terraces. In a rough way these terraces show different phases of rock structure and texture. Probably 50 feet represents the greatest thickness of strata shown at any one place. So far as has been seen, the outcrops lie wholly on the north side of the Minnesota River. The Cottonwood

¹ The Minnesota Valley in the Ice age, by Warren Upham: Proc. Am. Assoc. Adv. Sci., 1883, p. 216.

² Report intended to illustrate a map of the hydrographical basin of the Upper Mississippi River, by J. N. Nicollet; dated February 16, 1841: Twenty-sixth Congress, second session, Senate Doc. 237, p. 18.



GEOLOGICAL MAP OF THE COURTLAND DISTRICT

Scale



CRETACEOUS QUARTZITE GRANITE AND GNEISS

JULIUS BIEN & CO. LITH. N. Y.

River enters the Minnesota directly south of the locality. With its power for erosion this stream would have laid bare any high masses of quartzite lying between the elevated bluffs that bound it on either side.

Exposures near Redstone.—The exposure southeast of Redstone, in secs. 1 and 2, T. 109 N., R. 30 W., and secs. 35 and 36, T. 110 N., R. 30 W., is an extensive one. Here many steps can be seen in the transition from a loose, argillaceous and shaly sandstone to a vitreous quartzite; and again, from a vitreous quartzite of fine and uniform texture to a coarse quartzite conglomerate. The sandstones occupy the lower beds of the exposures, and the vitreous quartzite and quartzite conglomerates the higher beds. Yet there are no sharp divisions, many alternations of sandstone and quartzite layers occurring. The railroad cuts which penetrate these rocks 30 feet or more show that the quartzite is interbedded with the sandstone, and that the induration is not wholly a surface phenomenon.¹ There is a gradual ascent of the surface in passing away from the river, varying from 1 to 25 degrees, and many depressions bear evidence of unequal erosion, due to the unequal hardness of the rock, resulting in the terraces mentioned.

The highest portions of these exposures must be at least 175 feet above the Minnesota River. The erosion of the upper 50 feet is unquestionably due partly to glacial action, as grooves and striæ, still sharp and clear, show the direction of the ice currents, which, for this locality, was S. 33° E. But at places up to 125 feet above the point at which the lowermost shaly sandstone layers pass under the river, potholes and narrow tortuous grooves are numerous. This peculiar surface is clearly the result of the wear of running water rather than of moving ice; so the conclusion must be that the river's bed was once high up in this exposure, and that a large, muddy stream, with a rapid current, cut the gorges, gouged out the softer layers, wore the potholes, and chiseled into great irregularity the whole surface of the harder quartzite.

It is implied, in the statement of these erosive phenomena, that the wear of the rocks from the terrace 125 feet above the river down to the present water level has occurred since the Glacial period closed for this locality. That it has been accomplished since Cretaceous time is evident from the erosion of Cretaceous rocks in the neighborhood and within this same river gorge. The height mentioned, viz, 125 feet, certainly suggests the upper limit of erosion by water alone, and thus of post-Glacial work. The rocks are too hard to admit of rapid erosion.² The more complete preservation of the marks of

¹ On secondary enlargements of mineral fragments in certain rocks, by R. D. Irving and C. E. Van Hise: Bull. U. S. Geol. Survey No. 8, 1884, p. 34.

² Compare The recession of the Falls of St. Anthony, by N. H. Winchell: Geol. Nat. Hist. Survey Minnesota, Vol. II, 1888, pp. 312-341; The place of Niagara Falls in geologic history, by G. K. Gilbert: Proc. Am. Assoc. Adv. Sci., 1886, p. 222; Man and the Glacial Period, by G. F. Wright, 1892, pp. 361, 362; and many others.

water wear on the lower terraces may be due to the protection against glaciation afforded by the shelving rock surfaces which confronted the river gorge while the ice masses were pushed over them; yet the stronger probability is that this condition marks the stage of erosion when the final ice retreat passed this point. A recent study of the Dalles of the St. Croix by Berkey shows that a post-Glacial work has been accomplished by the St. Croix River¹ even greater than that at Courtland, both in its extent and in its significance as a measuring rod to apply to post-Glacial time.

In general the strike of the quartzites is N. 60° to 70° W., and their dip varies from 5° to 27° N. These figures are the average of a large number of observations in different portions of the area. There is considerable variation both in strike and in dip, even within restricted areas. The dip is more marked in the lower beds—those near the edge of the river—than in the uppermost beds now visible.

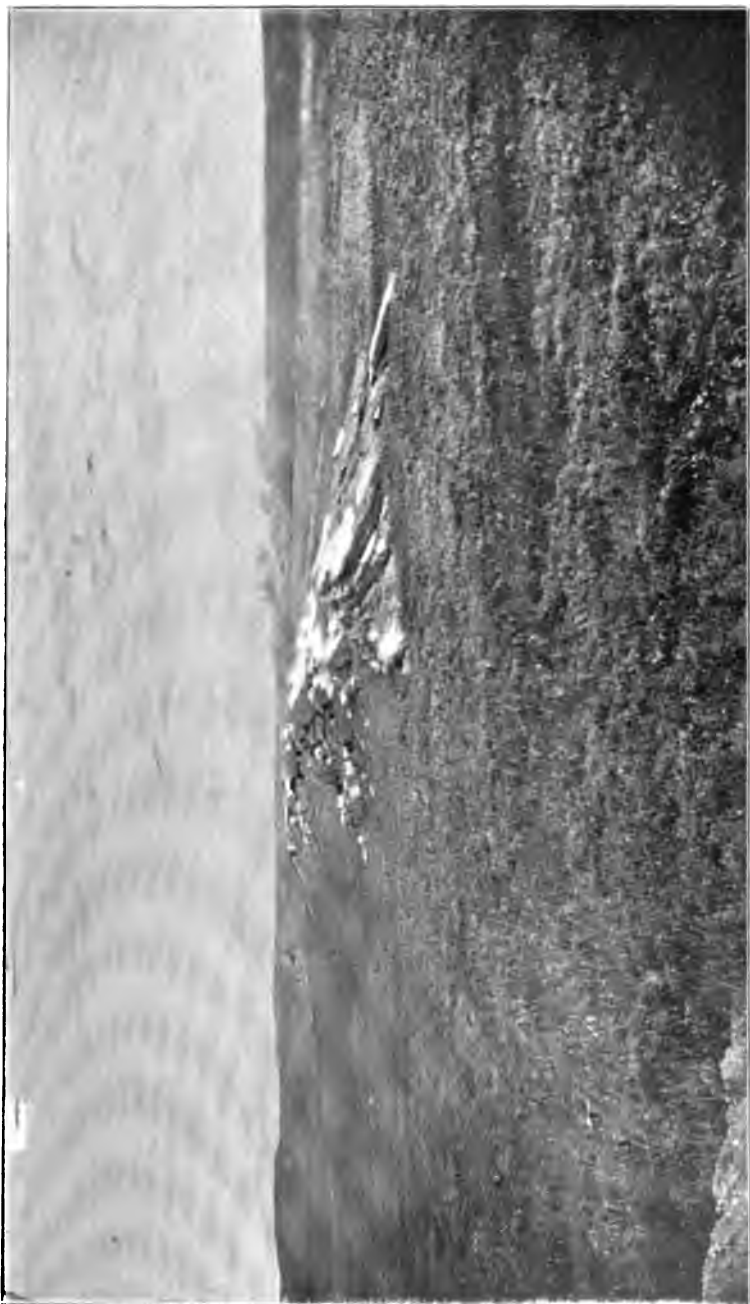
All the rocks have very high silica content. Often, indeed, they seem to be wholly silica, except for a small quantity of ferric oxide and calcium phosphate in the cement, solidifying the grains of clear quartz sand into a nongranular rock. Noting that Prof. James A. Dodge found distinct traces of calcium phosphate in the supposed new fossil, *Lingula calumet*, discovered² by Winchell in 1885 in the cat-linite interbedded with the red quartzite of Pipestone, Minnesota, a rock universally conceded to belong to the same horizon as this quartzite at Courtland, Mr. E. J. Babcock, now of the University of North Dakota, made tests for calcium phosphate in the Courtland quartzites. Five samples, showing no traces whatever of fossils, were taken from as many different parts of these rocks, representing the shale, the sandstone, the indurated quartzite, and the conglomerate of these beds, and qualitative analysis in all cases showed distinct traces of calcium phosphate. Some of them, and notably a sample of the conglomerate from near the top of the hill—that is, from the uppermost layers of quartzite exposed—yielded a very appreciable amount.

Microscopically, also, the quartzites show considerable diversity. The fine vitreous quartzite, as stated by Irving and Van Hise,³ shows the original fragmental grains coated with a film of oxide of iron and then enlarged, the cementing material becoming a constituent part of the reconstructed angular grains. In other places the indurating material is deposited independently as cryptocrystalline, partially chalcedonic quartz, with no regular orientation. There are still other places in which there seems to have been a cutting down of the original grains and the formation of a cryptocrystalline groundmass inclosing scattered and corroded grains of quartz. These latter places appear to be confined to the surface portions of the exposure

¹Geology of the St. Croix Dalles, by Charles P. Berkey: Am. Geologist, Vol. XX, Dec. 1897, p. 268.

²Notice of the discovery of *Lingula* and *Paradoxides* in the red quartzites of Minnesota, by N. H. Winchell: Bull. Minn. Acad. Nat. Sci., Vol. III, Pt. I, 1889, p. 103.

³On secondary enlargements of mineral fragments in certain rocks, by R. D. Irving and C. R. Van Hise: Bull. U. S. Geol. Survey No. 8, 1884, pp. 34, 35.



RELATION OF THE GNEISSIC SERIES TO THE BASAL CONGLOMERATE NEAR NEW ULM.

along the bedding planes and on the sides of the vertical joints, which have served as channels of percolation for subterranean waters. The silica thus dissolved and removed has doubtless acted as the indurating material for the underlying layers.

Exposures near New Ulm.—In sec. 27, T. 110 N., R. 30 W., near New Ulm, $1\frac{1}{2}$ miles northwest of the exposures near Redstone just described, lie large outcrops of coarse quartzite conglomerate. The strike and dip are nearly at right angles with the strike and dip of the quartzite southeast of Redstone; the strike near New Ulm, as roughly represented by the direction of the exposure, being N. 15° E., with a dip varying from 10° to 15° SE.

This rock is figured by Professor Irving, in his classic paper on Classification of the Early Cambrian and pre-Cambrian Formations, as an exposure of a typical basal conglomerate.¹

There is much variation in the coarseness of the pebbles, all sizes, from average sand grains to boulders 10 to 12 inches in diameter, being seen. These pebbles consist almost entirely of quartz, in part dull-red or brown jasper and in part clear white quartz. No quartzite masses were noticed possessing the characters of the quartzite southwest of Redstone, nor were any granitic pebbles seen.² This is somewhat surprising, in view of the close proximity of the granitic and gneissic rocks of the valley.

PROBABLE CONTINUATION OF THE QUARTZITE IN SURROUNDING AREAS.

There is evidence that the Courtland quartzites underlie a considerable belt of territory. Around Swan Lake (see Pl. I), from 4 to 6 miles northeast of the exposures near Redstone and New Ulm, boulders of red quartzite strew the ground in places. In Cottonwood and Watonwan counties, about 25 miles to the southwest, many square miles are underlain by vitreous quartzites, and many broad surfaces appear, representing a thickness of strata of at least 1,500 feet. The formation is, therefore, several times as thick as at Courtland, there being exposed at the latter place from 250 to 300 feet only.³ There is no doubt that the extensive exposures of red quartzites in Rock and Pipestone counties, Minnesota, and in many counties of southeastern South Dakota, belong to this same formation.⁴

To the eastward little is known of the extension of these beds. At Minneopa Falls, near Mankato, is a well 1,000 feet deep. In boring, at 575 feet from the surface a conglomerate was reached with pebbles of clear, fine, nongranular quartzite up to 2 or more inches in diameter.

¹ Seventh Ann. Rept. U. S. Geol. Survey, Pl. XLIV, facing p. 430.

² Compare paragraphs in Geology of Sibley and Nicollet counties, by Warren Upham: Geol. Nat. Hist. Survey Minnesota, Vol. II, 1888, pp. 157-160.

³ Preliminary paper on an investigation of the Archean formations of the Northwestern States, by R. D. Irving: Fifth Ann. Rept. U. S. Geol. Survey, 1884, p. 201.

⁴ Notes upon the geology of some portions of Minnesota, etc., by James Hall: Trans. Am. Philos. Soc., Phila., Vol. XIII, N. S., 1865, p. 338.

From this depth to more than 800 feet below the surface the borings consisted chiefly of quartzite pebbles indistinguishable in macroscopic and microscopic characters from the vitrified quartzites at Courtland.¹ These pebbles are essentially different from those composing the "basal conglomerate" beds opposite New Ulm.

In 1897, at Glencoe, about 35 miles north of Redstone, a well, bored for water, yielded drillings of a decidedly red color between depths of 936 and 1,640 feet. The rocks there penetrated were probably the northward extension, beneath the Paleozoic, of these Courtland quartzites.

AGE OF THE QUARTZITE.

The occurrence of the quartzite conglomerate at Minneopa Falls establishes the fact that the great Sioux quartzite terrane was thoroughly indurated and a subject of extensive erosion at the time the bottom beds of the Middle Cambrian were being laid down in the area now embraced in the Upper Mississippi Valley. (See fig. 4.)

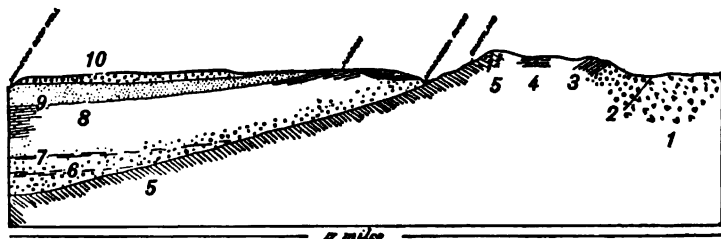
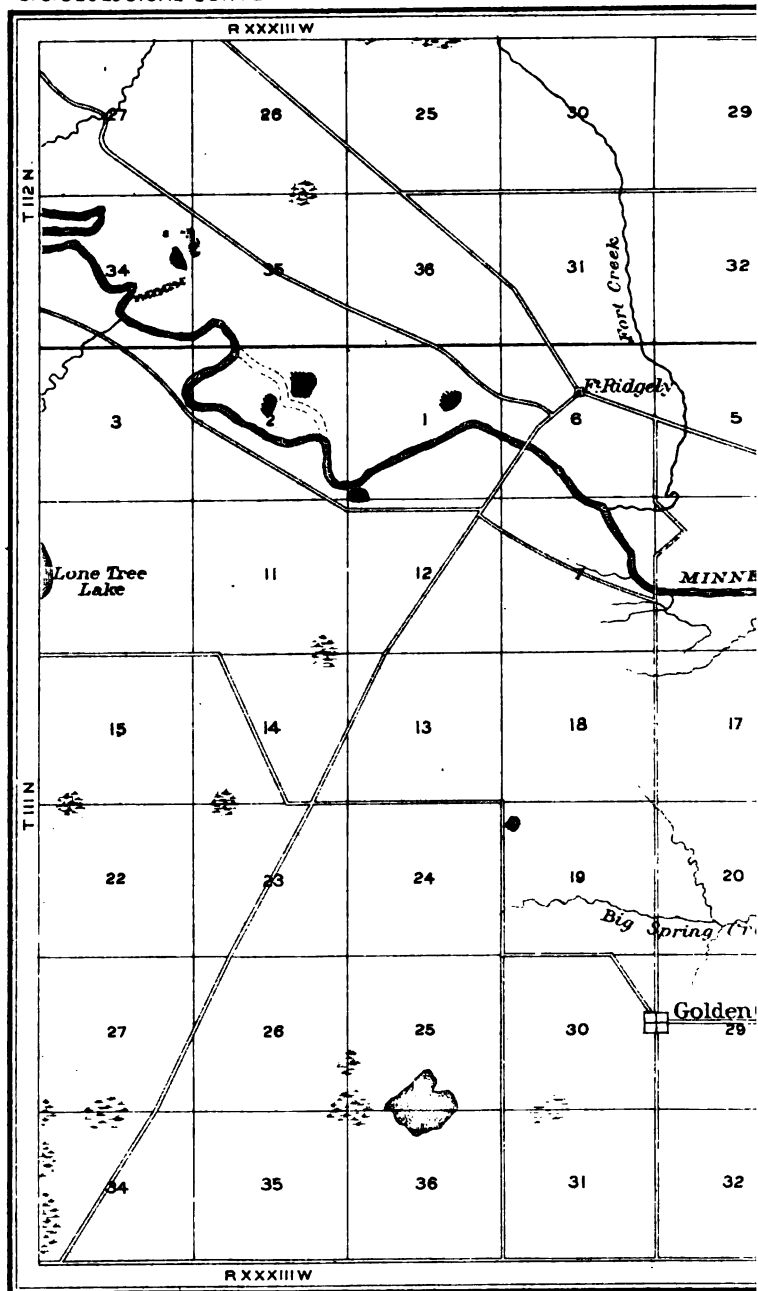


FIG. 4.—Hypothetical section from Courtland to Minneopa. 1, Granite-gneiss of the Minnesota River Valley; 2, Conglomeratic base of the quartzite formation; 3, Quartzite conglomerate much finer than at the base; 4, Concretionary Cretaceous limestone; 5, The Courtland exposures of red quartzite, with overlying conglomeratic phases; 6, Cambrian conglomerate with pebbles of red quartzite; 7, Dresbach (?) sandstone; 8, St. Lawrence dolomites and shales; 9, Jordan sandstone, seen at Minneopa Falls; 10, Glacial drift of varying thickness.

The lapse of an enormous interval of time between the deposition of the quartzites and the Middle Cambrian (Potsdam) is most strikingly shown by Irving for the Baraboo district of central Wisconsin, a district presumed by that writer to show features of age and stratigraphic relations identical with those of the Courtland district of southwestern Minnesota.² Whether these quartzites belong to the Upper Huronian subdivision of the Algonkian can not be determined from the mere fact of their lying unconformably beneath the Middle Cambrian. It is sufficient, for our present purpose, to know that a time gap of great length intervened between the deposition of these great quartzite beds and the close of the erosion which partly removed them and accumulated their débris as masses of conglomerate pebbles in the bottom layers of the Paleozoic of the Upper Mississippi Valley.

¹ The deep well at Minneopa, Minnesota, by C. W. Hall: Bull. Minn. Acad. Nat. Sci., Vol. III, No. 2, 1891, p. 248.

² On the classification of the early Cambrian and pre-Cambrian formations, by R. D. Irving: Seventh Ann. Rept. U. S. Geol. Survey, 1886, p. 403 et seq.

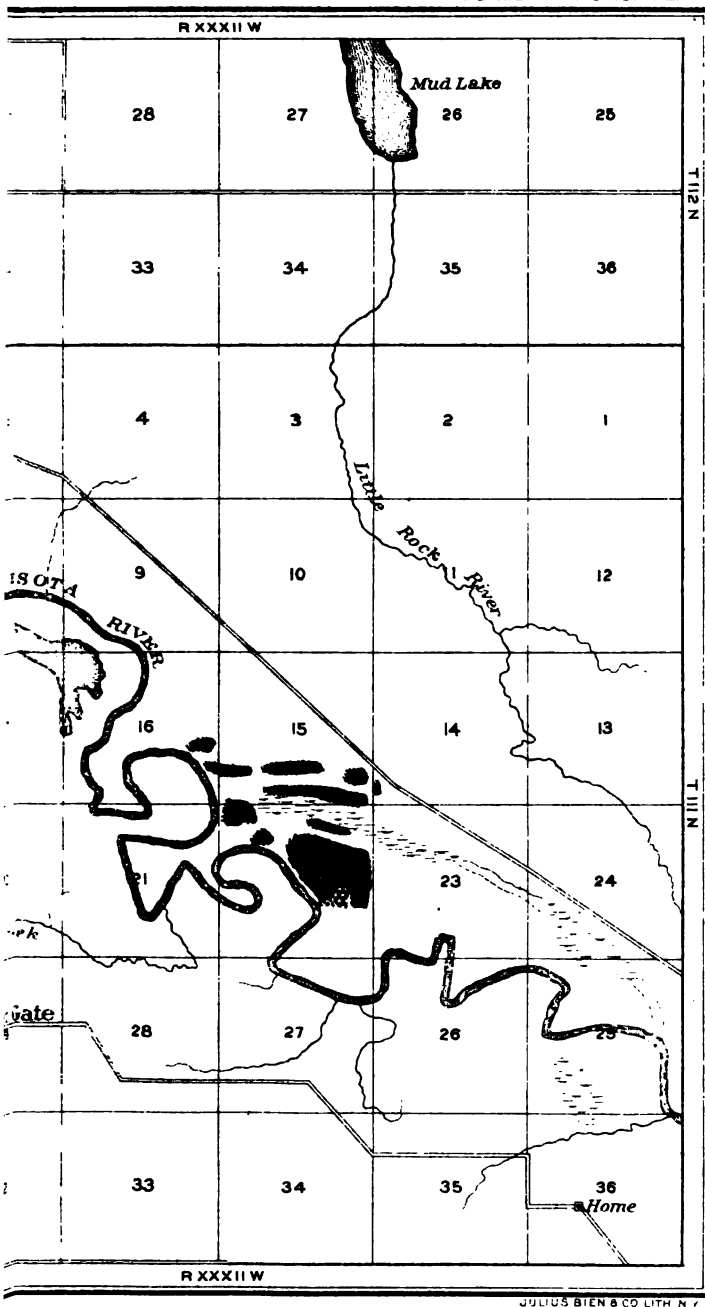


GEOLOGICAL MAP OF THE F

Scale



GABBRO AND GABBRO-SCHIST



FORT RIDGELY DISTRICT

1 2 MILES

GRANITE AND GNEISS

GNEISSOID GRANITE EXPOSURES.

One hundred and fifty paces west of the New Ulm conglomerate, and undoubtedly extending beneath it, lies the first outcrop of gneiss that is reached in ascending the Minnesota River Valley. Three or four knobs stand some 5 to 15 feet above the level of the river bottom. The several outcrops are shattered into numerous loose blocks by the forces of weathering. These blocks are so disintegrated and crumble so readily that hand specimens can with difficulty be shaped. They show all the phenomena of concentric weathering so common in disintegrating granites of coarsely crystalline texture. The shattered condition precludes the possibility of noting the strike or dip of the laminae. No contortion can be seen. The rock is granitic in texture, of medium coarseness, somewhat porphyritic, and of a reddish color, due to the abundance of red feldspars. It is hornblendic, but contains only a small portion of basic constituents and a much less proportion of quartz than the exposures farther up the river. The feldspars are orthoclase, microcline, and oligoclase, and are all considerably altered through kaolin, the orthoclase and the oligoclase to a much greater extent than the microcline. The altered areas are heavily charged with hematite and brown ferrite. The deepest specimens obtainable along the planes of fracture show a lodgment of ferric oxide, which in places is apparently hydrous (limonite). This lodgment is especially interesting around nests of basic constituents. In such places the intermingling of the brown and green gives a particularly weathered appearance, which is not, however, fully borne out by the microscopic examination.

FORT RIDGELY DISTRICT.

Passing up the river a distance of 15 miles from New Ulm, La Framboise's place is reached. This spot marks the beginning of some very extensive exposures of rocks. Here they come down to the water's edge, forming a good canoe landing and marking the spot where one of the earliest trading posts of the valley was located by the father of the present owner of the place.

GNEISSOID GRANITE.

Area northeast of Golden Gate.—In the area northeast of Golden Gate (Pl. IV), scattered over several sections in the vicinity, particularly over secs. 14, 15, 16, 21, 22, and 23, T. 111 N., R. 33 W., are many exposures of a gneiss which to a considerable extent is augitic and granitoid. It varies in texture, and over much of the area is so greatly shattered as to be unfit for systematic quarrying. Occasional areas are rather coarse, orthoclase crystals 5 or 6 inches in length being found, and in other areas a fineness unusual in gneissic rocks can be seen. As a rule, these exposures exhibit a rock of red color, but this color shades through pink to a dirty gray, and in some of the

exposures the last-named color is the predominant one. The more finely granular modifications are those of the gray color, and these carry augite. In all the rocks of this locality there is an unusual lack of biotite. Often hand specimens may be found on which not a folium of this mineral can be seen. The quartz is rather opalescent. The gneisses, as a whole, are characterized by a high per cent of silica.

Area west of Fort Ridgely.—West and southwest of old Fort Ridgely the gneiss assumes a darker color and a more pronounced gneissic habit through the increase of the biotite and the hornblende. It seems much fresher, and in places some quarrying has been done.

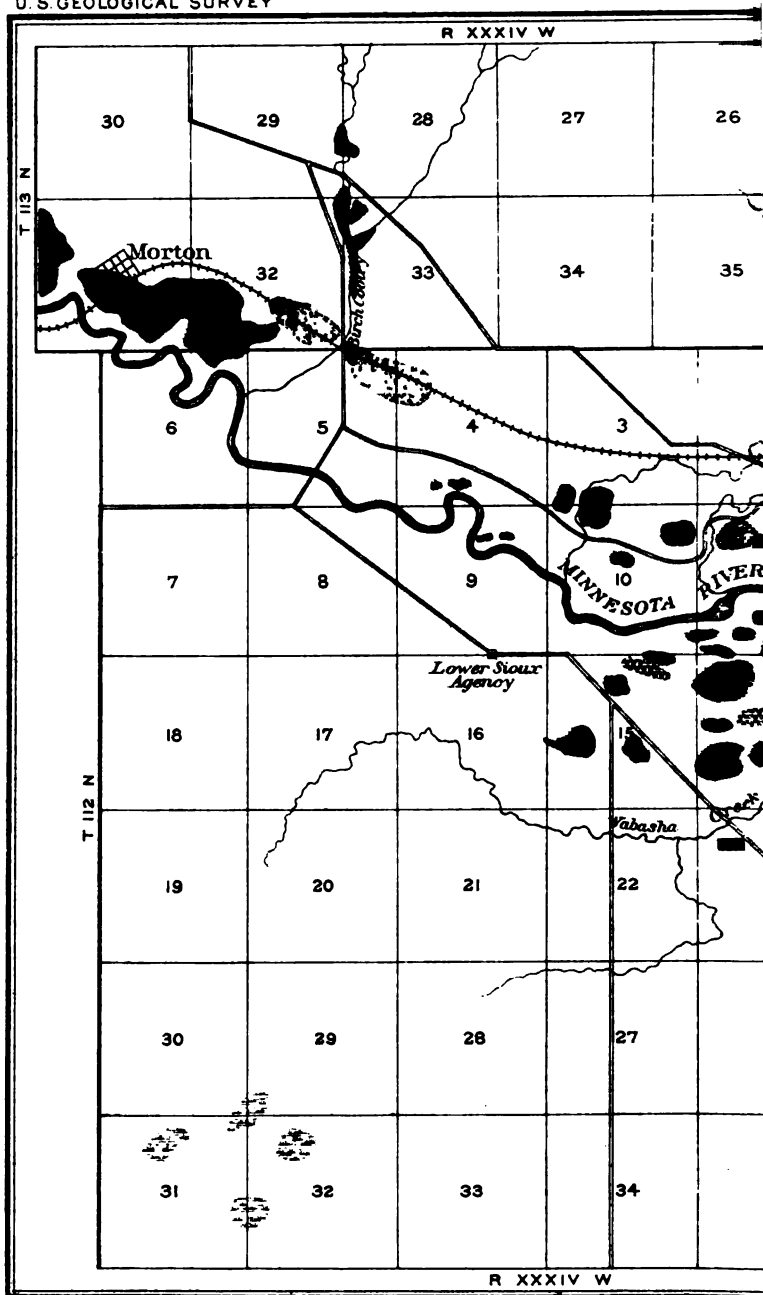
Along the south side of the river, within the area of the map (Pl. IV), several exposures of gneissic rocks are said to occur. The one locality visited was the old quarry out of which material was secured by the Government for erecting the barracks and other buildings of Fort Ridgely, whose ruins now stand upon a conspicuous morainic bluff on the north side of the river, $1\frac{1}{2}$ miles distant from the quarry. The location of this outcrop is at a sharp bend in the river, 150 paces N. and 1,900 paces W. of the southeast corner of sec. 1, T. 111 N., R. 33 W. It is 200 paces long by 150 paces wide. The rock is medium-grained gneissoid granite, porphyritic in texture, and is somewhat stained at the surface by weathering and the infiltration of ferric oxide along secondary structures. It is somewhat shattered, and in places is decidedly granitoid. The more laminated portions show some contortion of the bands, which have a general N.-S. strike, with a westerly dip of from 40° to 50° . In these respects the rock agrees with the masses on the north side of the river in secs. 35 and 36, T. 112 N., R. 33 W.

BASIC ROCKS.

In sec. 34, T. 112 N., R. 33 W., is a fine exposure of augite-schist. It can not be certainly determined whether it is a dike breaking through the gneiss or an interbedded layer of quite different mineral and chemical composition from the associated gneissic rocks, although it is probably the former. Only a few hundred paces northeast of the schist is a highly altered rock, now bearing epidote and calcite, which in both external and internal characters gives strong evidence of having once been an olivine-gabbro.

Near La Framboise's a hornblendic hypersthene-gabbro occurs in the augitic granitoid gneiss, and at the old Fort Ridgely quarries, NW. $\frac{1}{4}$ of NE. $\frac{1}{4}$ sec. 2, T. 111 N., R. 33 W., a hornblende-biotite-schist can be seen which doubtless was once similar in mineral composition to the hypersthene-gabbro at La Framboise's. It is probable that the gabbro just mentioned occurs as an intrusion in the gneiss. The contact between the two is sharp and clear where a wall is uncovered for a few paces.

Everywhere in the rocks of the Fort Ridgely district there are veins of quartz, and in places they are very numerous. For example, in sec.



GEOLOGICAL MAP OF THE

Scale



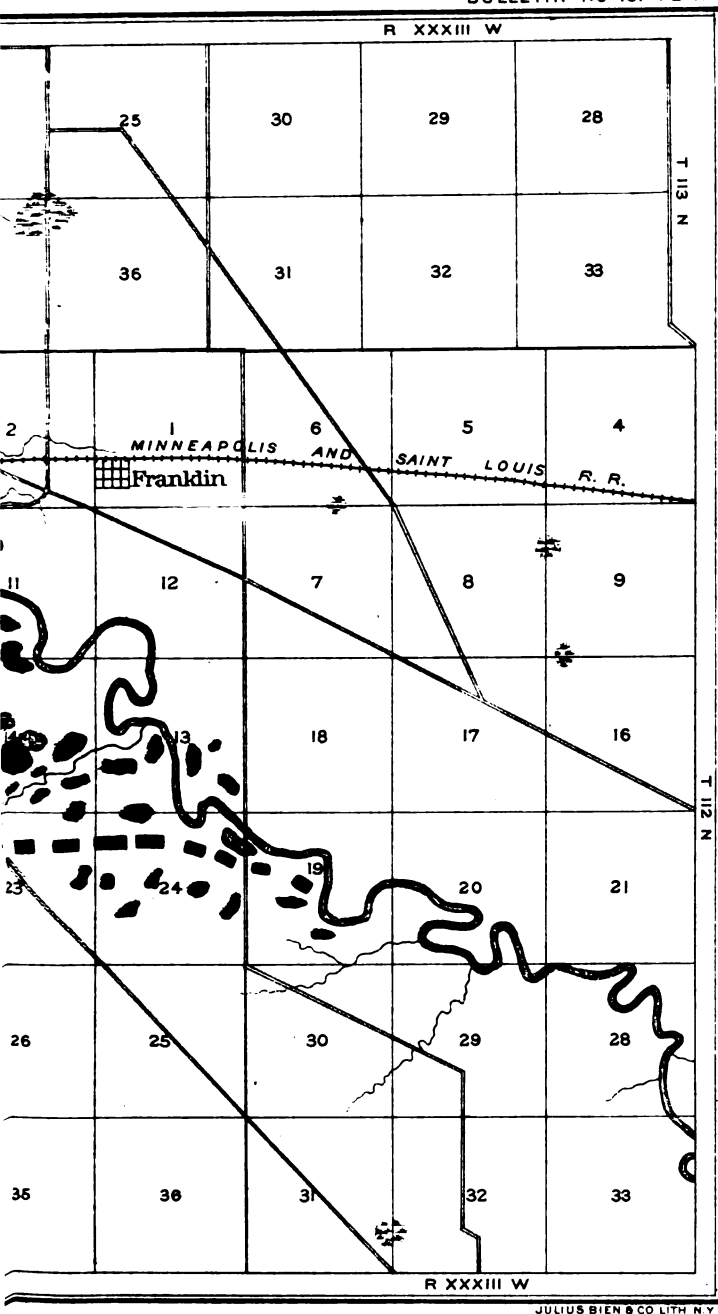
CRETACEOUS



DIABASE DIKES



GABBRO



MORTON DISTRICT

2 MILES

MO AND GABBRO-SCHIST

GRANITE AND GNEISS

2, T. 111 N., R. 33 W., running in a prevailing NW.-SE. direction, veins of milky quartz, varying in thickness from that of paper to 5 inches across and lenticular in shape, are seen to variegate the surface of the rock. Schistose inclusions are not infrequent. These possess a medium texture and vary somewhat in mineral composition.

MORTON AND BEAVER FALLS DISTRICTS.

PRE-CAMBRIAN ROCKS.

Lower Sioux Agency area.—In secs. 10, 11, 13, 14, 15, 23, and 24, T. 112 N., R. 34 W., on the south side of the Minnesota River, occur mound after mound of gneissic rocks, cut by diabase dikes and associated with altered gabbros and peridotites. In texture the gneissic exposures vary somewhat. On the average, the rocks are medium grained, but in places orthoclase individuals 4 inches across are found. Considerable contortion was noted in the lamination, but the general direction is NE.-SW. The number of veins and segregations is less than around Fort Ridgely. The gneiss adjacent to the large diabase dikes is of unusual freshness. This freshness seems to be an accidental character, for northwest of these exposures, in sec. 15 of the same township, the gneiss is badly weathered. This weathering and the already existing jointing of the rocks produce concentric blocks of various sizes, the uppermost and oldest being the most spheroidal. The gneisses are of the normal hornblendic biotite type. Accessories rather widely found in granitic rocks occur, particularly apatite, pyrite, and magnetite.

On the Tracy farm, in sec. 10 of this same township, a beautiful chloritic gneissoid granite is found, not in large quantity, but with beautiful areas of radiated chlorite and chlorite plates in vermicular chains. (Pl. XVII, A.) This rock carries many inclusions of a dark-green color, which show a predominating quantity of chlorite.

In sec. 14 of the same township are large masses of a coarse-grained, dark-colored, hornblendic rock. There is a foliation in a general NE.-SW. direction and a southeasterly dip of 80°, although at the surface there is much contortion. This is evidently an altered gabbroid rock.

In sec. 19, T. 112 N., R. 33 W., and secs. 23 and 24, T. 112 N., R. 34 W., lies the largest clearly defined dike, save the one at Pigeon Falls, which the writer has seen in Minnesota.¹ Its width is 60 paces, and it can be traced 2 or 3 miles across the valley, standing in the midst of a large mass of fine, fresh, gray gneiss. In composition it is a badly altered quartzose diabase.

In sec. 15, associated with the gneiss, is a hornblende-augite-schist which contains some hypersthene.

¹ This dike, crossing the Pigeon River and forming the falls named, has been described by Norwood in Owen's Report of a Geological Survey of Wisconsin, Iowa, and Minnesota, etc., Philadelphia, 1852, p. 405; and has been referred to by Irving in The copper-bearing rocks of Lake Superior: Mon. U. S. Geol. Survey, Vol. V, 1883, p. 371.

In sec. 9 of the same township occur the only peridotite and serpentine seen in place in the Minnesota River Valley. Two low knobs, each 100 paces long, 50 paces wide, and not exceeding 10 feet in height, represent all of these rocks. The variety of peridotite seems to be saxonite, although somewhat altered. The numerous cavities in the rock are filled with geodized incrustations of amethystine quartz and, more rarely, resinous-looking calcite.

In the more exposed portions the alteration mentioned has proceeded until the original constituents have wholly disappeared. Indeed, a set of rock sections may be prepared showing every degree of alteration from a nearly normal peridotite, with only slight alteration of its enstatite and olivine, to a serpentinous rock in which not a trace of the original constituents remains.

While these knobs of peridotite are the only occurrence of the rock undoubtedly in place, it may be added that in secs. 32 and 33, T. 112 N., R. 33 W., between the foot of the morainic bluff and the present bed of the river, stands a terrace in which are many boulders of peridotite and serpentine. The present condition of these boulders points to the probability that they have been transported but a short distance, thus leading to the inference that beneath the glacial drift and the

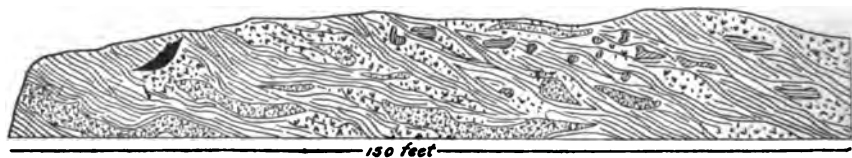
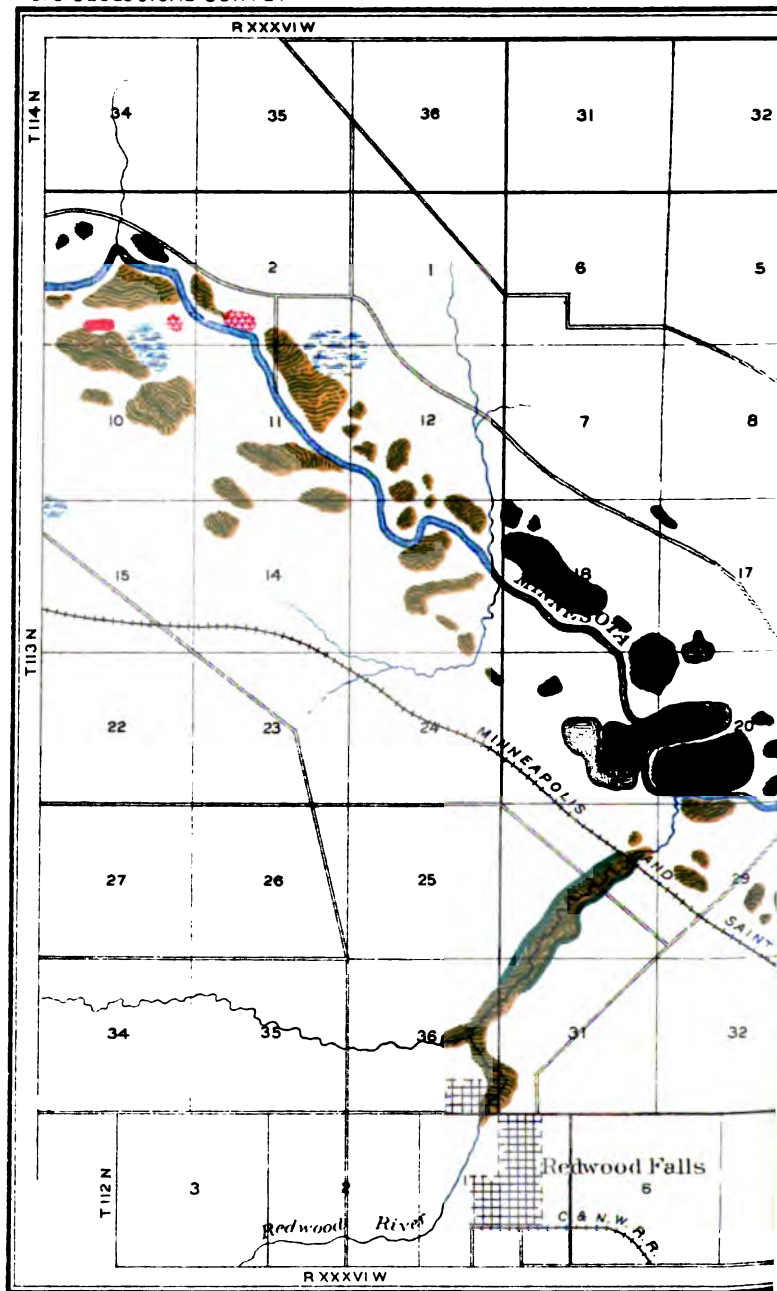


FIG. 5.—Contorted hornblende-biotite-gneiss, from railway cut at Morton, 150 feet long.

deposits of river débris there lies a large mass of these heavily basic rocks. Every petrological character is identical with the corresponding one of the rocks in situ in sec. 9, already mentioned.

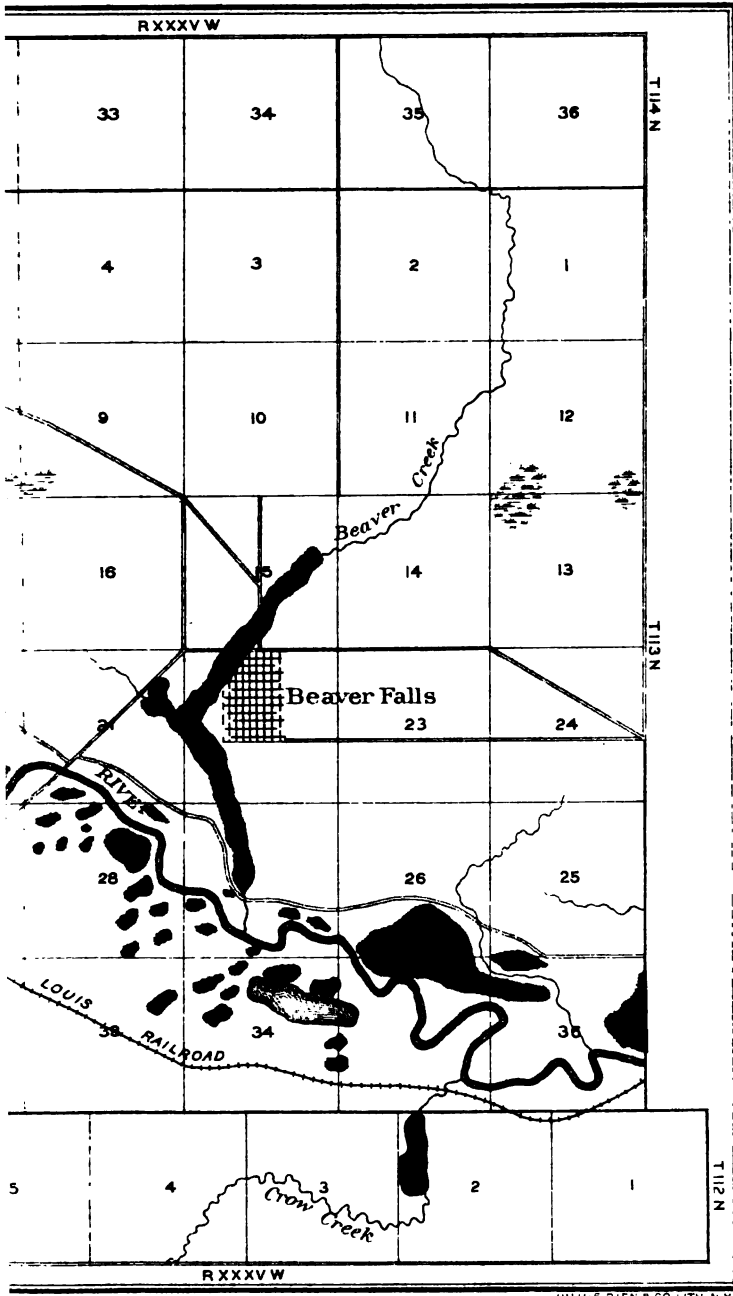
Morton area.—At Morton appear huge mounds of gneiss with a contorted lamination. (Fig. 5.) This gneiss is hornblendic, and has a pre-vaillingly dark color. In places nests of pyrite can be seen on freshly fractured surfaces. In coming up the river from La Framboise's to this place we see a gradual change in the color of the gneissic rocks from a reddish to a prevaillingly dark gray, a change from the granitoid structure to the gneissic, a disappearance of the augite-bearing rocks lean in basic minerals, and the appearance of nonaugitic gneisses in which both hornblende and biotite are abundant. The foliation of these rocks in all its contortions can be seen on the surface wherever weathering has not so corroded it that part of the constituents are no longer visible. The railroad cut at Morton shows a fresh surface. The accompanying figure (fig. 5) was taken from the west side of that cut. Attention may be called to the coarsely crystalline masses of pegmatite which are rather thickly distributed throughout this fresh Morton gneiss. These masses are not so clearly defined as are pegmatitic



GEOLOGICAL MAP OF THE

Scale





BEAVER FALLS DISTRICT

2 MILES

RO AND GABBRO-SCHIST



GRANITE AND GNEISS

veins, but their general characters indicate them to be such. In almost all cases noted they merge insensibly into the normal gneiss. In places they carry nests of biotite and hornblende, many of which are 1 or 2 inches across.

Veinlike segregations of feldspar and quartz and of quartz alone are everywhere numerous. They are not marked by unusual size, nor by the occurrence of metallic contents. There is no little diversity, however, in mineral constituents, as well as in texture and structure. On Birch Cooley some finely textured reddish veins of true granitic type show a distinctly laminated structure. They are irregular in shape and direction. Elsewhere a pegmatitic structure prevails. In the altered portions of the gneissic rocks the veins, which are also altered, carry numerous scales and pockets of limonite. These altered veins show much variation in color and texture. In many large areas, where the color is pink or reddish gray the feldspars are abundant, and where reddish black the biotite and hornblende occupy a larger place than usual. These characters are particularly noticeable at the exposures in secs. 29 and 30, T. 113 N., R. 35 W., north of the city of Redwood Falls.

The tops of the large mounds of gneiss at Morton, 75 feet above the high-water mark of the present Minnesota River, display indubitable evidences of water erosion. For the most part these surfaces are smooth and rounded, but on the very top of the highest hill a pothole of considerable size still exists. Grooves cut by running water can also be seen.

At Morton (Pl. V) the gneiss is, in places, remarkably fresh. Ordinary metamorphic changes, as Geikie defines the term,¹ are everywhere met with among these rocks. In a few places changes are noted which can be traced directly to surface influences; also changes which have removed so much of the rocks that what is now left has every character of an entirely different species. The kaolin beds of the Birch Cooley Gorge are a case in point, because there is no doubt that these beds are altered gneissic rocks which at one time presented characters similar to, if not identical with, those of the gneisses at Morton which are now so fresh and firm. There is little doubt that the Birch Cooley exposures are portions of the same beds that appear at Morton.

Beaver Falls area.—(Pl. VI.) Along the bottom lands of the Minnesota River, northwest of Morton, the gneissic rocks appear in large, high knobs. The higher and more exposed portions of these outcrops are comparatively fresh and firm, while in the more sheltered places the kaolinized portions are not yet removed. A distinctly gneissic habit prevails, with less contortion than appears around Morton. The strike of the laminæ is NW.—SE., and the dip is NE., with a varying angle. While in general there is little difference in character between

¹Text-book of Geology, by Archibald Geikie, 3d ed., 1893, p. 595.

the gneiss of the knobs between Morton and Beaver Falls and the quarried rocks of Morton, slight differences may be noted. The porphyritic character of the gneiss at Beaver Falls is rather prominent. Feldspar crystals, orthoclase and microcline, are well defined. In size they reach a length of 2 or more inches. They show Carlsbad twinning, are much fresher than the finer-grained matrix, and resist weathering to such an extent that they stand out from the surface of the rock a half inch or more. Their whitened aspect indicates the kaolinized condition which even the freshest individuals exhibit. The gneissic, porphyritic condition which has just been noted is not uniform. In places a pegmatitic structure covers extensive areas. These coarser phases are at times sharply defined, and again pass gradually into the normal biotitic gneiss of the area. In some areas finer granitic veins are frequent, similar in texture, color, and mineral composition to those seen on Birch Cooley Creek, in the Morton district, penetrating the fresher phases of the gneisses.

The surface material of the gneisses shows no appreciable amount of hornblende, almost all of the basic portion being biotite.

Joints are everywhere very conspicuous upon these mounds. In places they have produced nearly perpendicular walls. This is not noticeably the case on the southerly face of the large mound which crops out in secs. 26, 35, and 36, T. 113 N., R. 35 W. The usual direction of the joints is N. 35° W. A waterworn condition of the surface is rather marked. Even the highest portions of the mound referred to, from 30 to 50 feet above the river's present level, show potholes and grooves which bear conclusive evidence of water wear rather than of the even cutting of glacial ice. These phenomena of water action are not so conspicuous at this locality as on the summits of the quartzite areas at Courtland, described on page 21, nor so numerous as at several localities farther up the river (pp. 36, 42).

Along the river road from sec. 26, T. 113 N., R. 35 W., westward to Beaver Creek, there are a number of unimportant weathered exposures of the same general character as those above described.

Redwood River area.—Near the mouth of the Redwood River (Pl. VII) the gneisses, showing a typical, distinctly laminated, and uncontorted structure, appear in large areas and cause many tortuous windings in the Minnesota River. The strike is NE.-SW., in places N. 75° E., with a dip sometimes as high as 70° SE. The lamination at this point is conditioned by the parallelism of the constituent minerals. At the northern border of this area of gneissic rocks there is an intercalation of hornblende-schist. It is characterized by a rather coarse texture (sp. 5260), and consists chiefly of quartz granules, triclinic feldspars, and green hornblende, the last occasionally carrying cores of augite. It bears many evidences of descent from the bedded gabbros of the valley. Numerous feldspathic veins form an anastomosing network throughout the whole exposed area of this rock.



REDWOOD RIVER FALLS.

Near the Redwood River, from its mouth to the falls in the city of Redwood Falls, there are many places where the altered gneiss is prominently exposed to view. One spot shows such a complete kaolinization, and at the same time such a staining by ferric oxide, that considerable material has been extracted for the manufacture of brown mineral paint. In sec. 29, T. 113 N., R. 35 W., some quarrying has been done in a gneissic rock which in state of preservation stands about midway between the rock just mentioned as serviceable for a paint and the fine, fresh gneiss at Morton and above Beaver Falls.

The Redwood River has cut a picturesque gorge for itself for a distance of from $1\frac{1}{2}$ to 2 miles from the south wall of the old River Warren to the present Redwood Falls.¹ The walls of this gorge are massive gneissic rocks, reaching 150 feet in height. In all the places cited above almost every stage of decomposition may be seen, from the freshest and finest gneiss down to the impure green kaolin of Birch Cooley, or the "red paint" below Redwood Falls. Usually the quartz constituent of the gneisses is quite fresh and holds its place in lenticular laminae through the soft material which now makes up the mass of the rock exposures.

Area above Redwood River.—Along the river bottoms above Beaver Falls and Redwood Falls, on both sides of the Minnesota River, there are numerous exposures of biotite-gneisses. In secs. 19 and 20, T. 113 N., R. 35 W., are some large and high rock masses which have to no little degree modified the course of the river, as a glance at Pl. VI will show. In the southeastern corner of sec. 20 are some notable mounds, caused by concentric weathering. Spherical masses of tons' weight lie around. The rocks are, as a rule, of a decidedly fresh aspect; a few are thoroughly disintegrated at the surface, yet have considerable consistency and toughness at the center. They are well laminated. The gneisses exhibit very little variation from the types in the southeastern portion of the Beaver Falls district (Pl. VI). But interlaminated with the hornblende-biotite-gneisses are some interesting hornblende-schists. The schists weather rather more rapidly than the gneissic rocks, and as a consequence they are found in the lower portions of the exposures. They show some variation in texture, in some cases a rather coarse condition being prominent. The structure and mineral composition of the schists are distinctly gabbroid. Hornblende and a plagioclastic feldspar close to labradorite in its optical characters are the chief constituents. The form and structure of these minerals are the same as in ordinary hornblende-gabbros, the only difference being in the complete alteration of the pyroxenic into amphibolic constituents. The strike of the rocks, gneisses and schists alike, where it shows any regularity, is NE.-SW., and the dip is SE. But in places there is great contortion.

¹Compare Geology of Brown and Redwood counties, by Warren Upham: Geol. Nat. Hist. Survey Minnesota, Vol. I, p. 564.

Origin of kaolinic gneisses.—It may be well to note here the altitude of the kaolinic gneisses, as compared with that of the fresh gneisses, at Morton, Beaver Falls, and several other places along the valley where the fresh rocks and the kaolinic varieties are found. Nowhere does the kaolinic stand at a greater altitude than the undecomposed rock at some place in the immediate neighborhood. At Morton the knobs of fresh gneiss in secs. 30 and 31, T. 113 N., R. 34 W., must reach an elevation at least 100 feet higher than the kaolinic gneiss in the Birch Oooley Gorge. At Beaver Falls dam the fresh, bright hornblende-biotite-gneiss is certainly 75 feet higher than the decayed material beside the road running along Beaver Creek, between the village of Beaver Falls and the Minnesota River bottoms. The same relative altitudes are shown in the gorge of the Redwood River between Redwood Falls and the Minnesota River, and, although to a less degree, near the village of Minnesota Falls and in the city of Granite Falls.

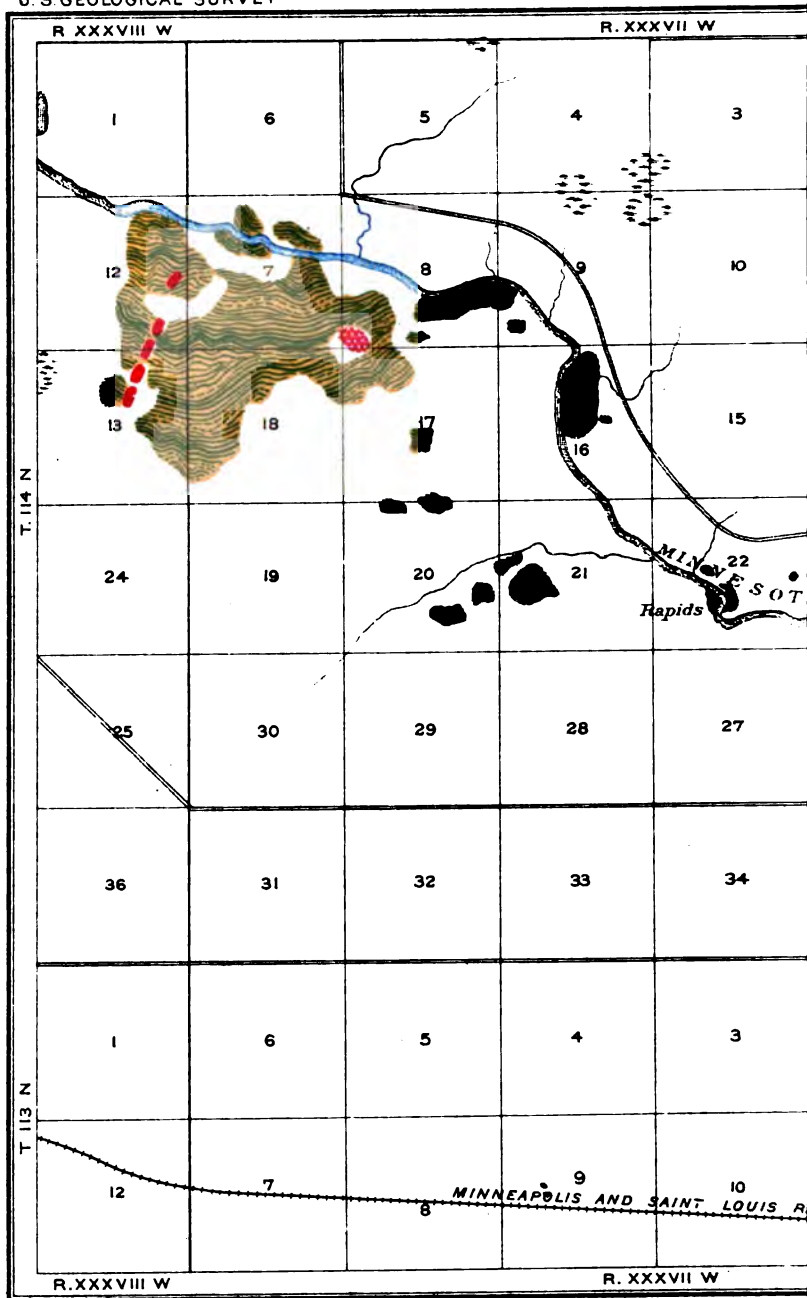
These facts of position tend to show that in the decomposition, which must have been pre-Glacial, the breaking up of the old crystalline rocks could not have been a leveling process, as we understand that term, but that, either through a difference in the hardness of the rock or by reason of other qualifying circumstances, the corrosion reached to great depths in certain places, while in others near by but little effect was produced.

VICKSBURG DISTRICT.

Continuing in a northwesterly direction up the Minnesota Valley (Pls. VIII and IX), there is found, in T. 114 N., R. 36 W., and especially in that portion lying on the north side of the Minnesota River south of the post-office of Vicksburg, an extremely rocky area. The valley here broadens to 4 or 5 miles, with large areas so rock covered that these sections were marked by the land surveyors as "rock barrens." The rocky mounds stand high and bare. Their tops, from 50 to 100 feet above the present river, show many potholes and tortuous grooves from river erosion. As one enters this township from the southwest he finds an extremely interesting series of gneisses and schists. The former are rather acidic in composition, carrying hornblende as the chief basic constituent, and the latter are gabbro-schists of somewhat varying types.

GNEISSES.

Taking the district as a whole, the strike of the gneisses is NE.-SW. Their dip, according to several measurements below Redwood Falls, is SE. at an angle of 70°, while elsewhere the angle was as low as 25°. The general direction of these rocks, both in strike and in dip, is shown on the maps by dotted lines. The gneiss is, as a rule, highly siliceous and strongly banded, 27 laminae having been counted in a single inch. It is not so contorted as the gneiss around Beaver Falls and



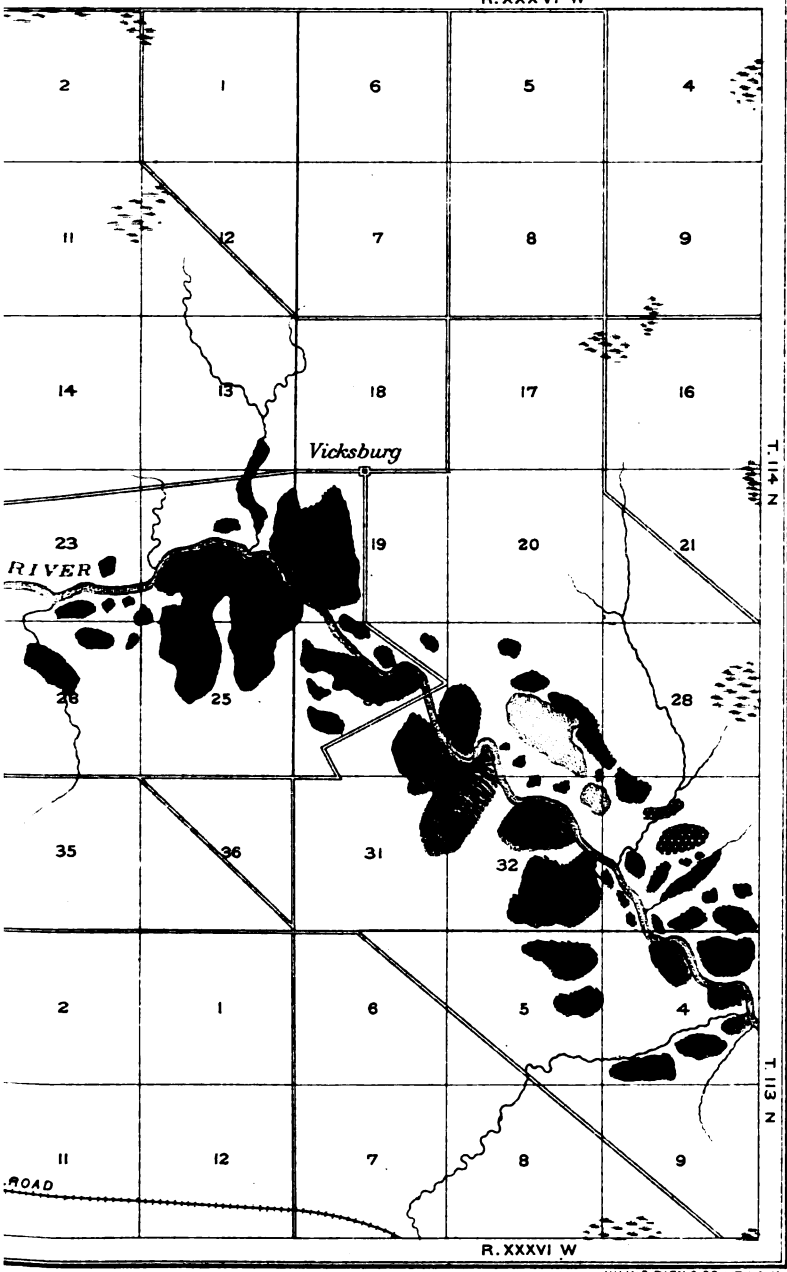
GEOLOGICAL MAP OF THE

Scale



DIABASE DIKES GABBRO AND

R. XXXVI W



VICKSBURG DISTRICT

0 1 2 MILES

ABBRO-SCHIST GRANITE AND GNEISS



ROCK EXPOSURES IN THE CENTRAL VALLEY, VICKSBURG DISTRICT.

Morton. In places it is quite epidotic, and almost everywhere it is porphyritic.

In the almost continuous series of exposures in this vicinity the rocks present great diversity of type. In places the gneiss is so massive that no lamination is seen for several feet, while not far away, it may be, a decidedly schistose habit prevails. Large areas are seen with few traces of veins, whether granular or quartzose, while in other and contiguous areas veins are so numerous that scarcely a square inch of surface can be seen which does not carry these segregations. Some rock masses are very fine in texture, while others are coarse and crumbling. Many of the gneisses show an abundance of quartz and potash feldspars, with only a small proportion of the basic minerals, hornblende and biotite; elsewhere hornblende and plagioclases constitute the bulk of the rock, with almost no quartz present. Some stretches of rock surfaces present a prevailing red color, while others are a decided gray.

In several exposures of the gneisses pyrite and chalcopryite were seen as accessories. Rarely the latter occurs in sufficient quantity to give a gray or blue color to its associated minerals through the alteration to carbonate of copper.

In one locality, in sec. 8, T. 114 N., R. 37 W., on these same rock barrens, occurs a rock of much interest (sp. 5372, 5373, 5374), which is fully described later (pp. 69-72). It is an augite-biotite-granite-gneiss of not very great extent. The grain is coarse, and the color is a mottled dark green and light green. Streaks of a veinlike mixture of feldspar (microcline) and hornblende appear, with individuals 3 and 4 inches across.

GABBRO-SCHISTS.

In the gabbro-schists associated with the gneisses we have rocks quite different in many of their aspects from either ordinary gneisses or ordinary schists. In texture the schists are medium to fine, and in structure they are distinctly laminated. The strike of the lamination is NE.-SW., and the dip is 25° SE. The rocks are laminated gabbros, and so far as general characters are concerned they appear much like the flaser-gabbros of the German lithologists, particularly those described by Lehmann.¹ These gabbroid rocks must be very ancient, since they are broken through by the diabase dikes so common in the valley, and are apparently interbedded with the gneisses with which they are associated. They will be described further in Chapter V.

In this vicinity, in sec. 33, a white variety of hornblende—tremolite—was seen in one rock, an occurrence somewhat rare in the valley. Near it occurs a garnetiferous hornblende rock which carries diallage, the mineral from which, by its alteration, a portion of the white hornblende springs.

¹ Entstehung d. altkryst. Gesteine, 1884, p. 194.

GRANITE FALLS DISTRICT.

Directly on the line between T. 115 N., R. 38 W., and T. 115 N., R. 39 W., in sec. 19 of the former and in sec. 24 of the latter (Pl. X), gabbro-schist occurs. The rock stands in nearly vertical position. It is so shattered that measurements of strike and dip are somewhat uncertain. The strike was determined as N. 65° E., the dip being SE. at an angle ranging from 75° to vertical. The texture is very fine, and geodized masses of quartz occur. Only one other place is known in the valley where a schist as finely textured as this occurs in place. That is in sec. 17, township of Omro, 115 N., R. 43 W. This peculiar rock is not infrequent in the form of drift boulders in various parts of Minnesota. Large masses have been found at Litchfield, T. 119 N., R. 31 W., at Minneapolis, and at many other places. These occurrences point to a somewhat wide distribution of this hornblende-schist beneath the drift.

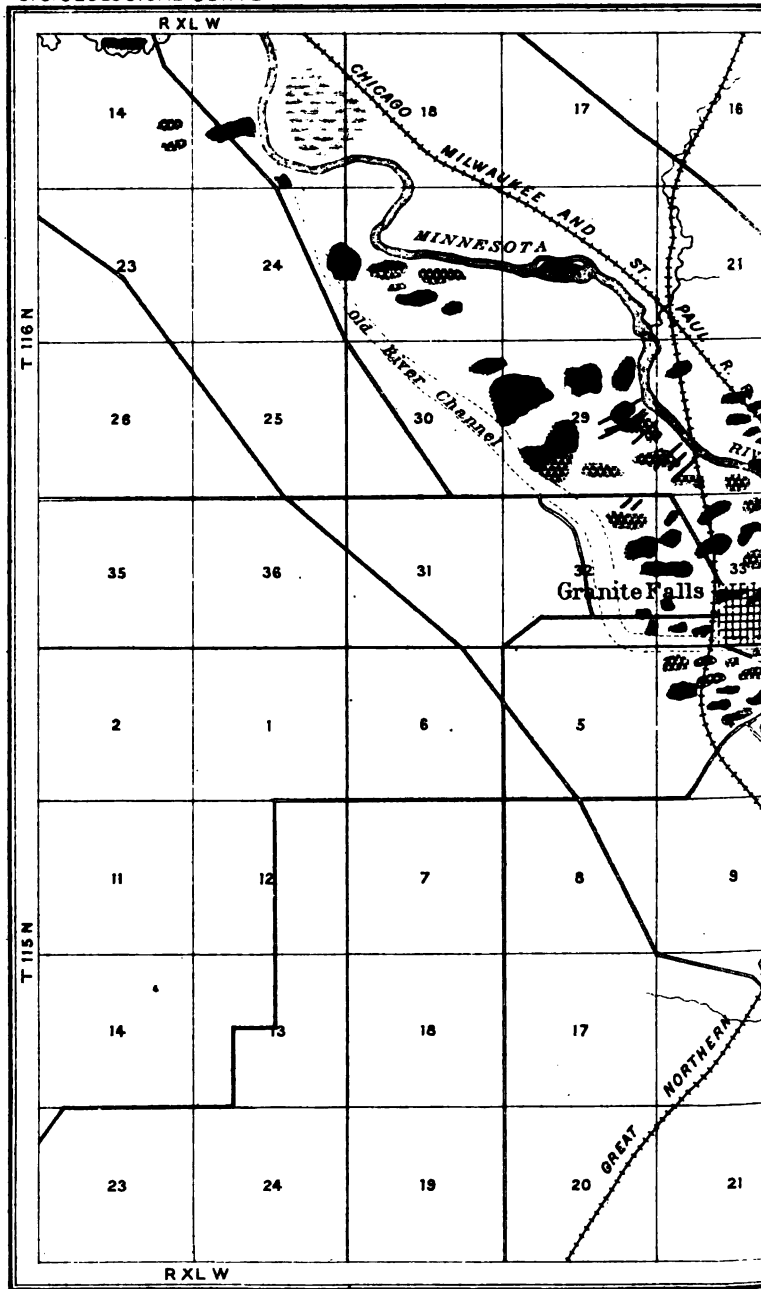
A mile and a half northwest of these gabbro-schists of secs. 19 and 24 begins an interesting series of gneisses, diorites, and pyroxenic schists of a markedly gabbroid character. Through Minnesota Falls and Granite Falls a succession of folds can be traced in which this series of interbedded gneisses and schists dips alternately S. and N. at angles usually less than 35° . To the south of Minnesota Falls the dip is southerly, changing to northerly in Minnesota Falls itself. In Granite Falls the dip again changes to a southerly direction, and this in turn gives place to a northerly dip, as the long series of billowy masses of crystalline rocks finally disappears under the masses of glacial drift and river silt which conceal all the rock exposures between the northern part of Granite Falls and Montevideo.

The gneissic rocks take the leading place in point of area underlain. In texture and composition they exhibit some modifications which are of interest. They are nowhere granitoid. The lamination is clear and distinct, with a strike varying little for many miles, being ENE.-WSW. The color is gray or reddish gray, and the texture medium grained. The proportion of quartz among the mineral constituents is very high. The feldspathic constituent is largely plagioclastic, of the soda-lime variety, and in places is somewhat kaolinized, thus giving a bleached appearance to the mineral. The kaolinization seems to pervade orthoclase and plagioclase alike. The basic minerals are both hornblende and biotite, the former predominating.

On the north side of the river, in sec. 28, T. 116 N., R. 40 W., a great many small garnets appear within the gneissic rocks. These show all stages of alteration into biotite; and biotite remote from the garnet patches is comparatively rare.

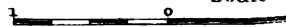
Inclusions and bands of hornblende-augite-schist are rather frequent in the gneisses.

As shown by microscopical examination (see pp. 85-93) the dark-colored rocks of this locality are schistose gabbros. So far as can be seen these schistose gabbros conform in position with the gneisses and



GEOLOGICAL MAP OF GRANITE FALLS, MINN.

Scale



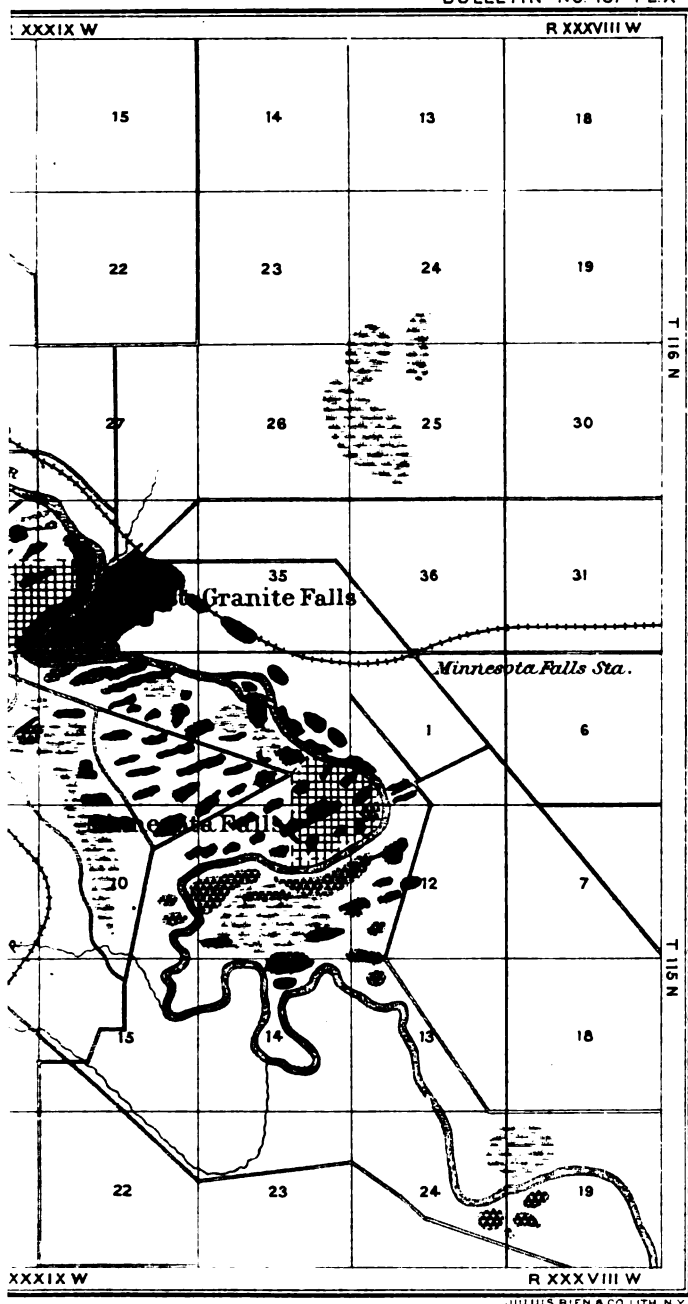
CRETACEOUS



DIABASE DIKES



GABBRO INCLUSIONS



JULIUS BIEN & CO LITH. N.Y.

GRANITE FALLS DISTRICT

1 2 MILES

DIOBASE AND GABBRO-SCHIST
DIOBASE AND GABBRO-DIORITE

GRANITE AND GNEISS

diorite-schists. They carry numerous garnets. At the surface the augite is, to a considerable extent, altered to biotite. It is probable that the garnets also, by their decomposition, have added materially to the amount of biotite present in the rocks. In the deeper beds the schists have a fresher look. They carry little biotite, but are rich in hornblende. A heavy stain of ferric oxide is everywhere present on the weathered surfaces, both of the surficial rock and along internal fractures exposed in quarries and railway and highway cuts.

Evidences of water erosion, potholes, tortuous grooves, etc., are found at a considerable height above the present river.

This district can not be passed without mentioning the bed of gabbro-schist, described in detail on pages 87 and 88, which occurs in sec. 32, T. 115 N., R. 40 W., 1,750 paces N., 250 paces W. It covers an area of small extent, the exposed surface being only 25 paces long and 20 paces wide. Over its whole surface this rock is profusely veined. While its contact with the surrounding rocks can not be seen, it is no doubt conformable with the beautifully contorted gneiss which stands out to view only 40 paces to the north. The gabbro-schists throughout the district present as pronounced a lamination as do the gneisses themselves. In color they vary from dark green to black, and they fade out very perceptibly on weathering. These rocks are further described on pages 85-93.

All the rocks, gneisses and gabbro-schists, are cut through by the dikes. The number of dikes crossing the valley through this district is large. There is great diversity in their width as well as in their massiveness and texture. They have one general direction, from the northeast to the southwest, but locally the direction varies to some extent. All these dikes are diabasic, or were originally, although many of them are now much altered. The change is more marked in the southern portion of the area. This difference may be due to a long time interval between the intrusion of the dikes of the southern and northern areas.

Veins are frequently seen in all the different rocks of this district. The coarse granitic material of several of the veins is noticeable, while the milky quartz veins, which are not infrequent, have been found to carry traces of gold. Much quartz, in lenticular masses or segregations, is to be seen in these rocks, as well as in the deposited masses in the areas bordering the fissures.

While there is no evidence at hand to show that the rocks of this district are eruptive, all indications, if any ever existed, of a sedimentary origin for any of them, whether basic gabbro schists, semi-basic diorites, or acidic gneisses, have been obliterated in the subsequent transformations through which they have passed. The characters of every class of rock in the area are such that most geologists would regard them as evidence of eruptive origin. All evidences of any different condition at any previous geologic period point to the alteration

of some other crystalline rock rather than to the upbuilding from an originally clastic mass into the present perfectly crystalline condition. Still, no undoubted evidence of eruptive origin exists here. Lawson has pointed this out¹ in the case of similar rocks in his upper division of the Archean rocks of Ontario.

The area about Minnesota Falls has been, at least twice within its geologic history, the scene of profound volcanic disturbances. At the first, great quantities of rock were intruded. At least a portion of these rocks was basic. During the profound foldings which the Archean crust has undergone throughout the entire Northwest, these rocks were made schistose and were infolded with the associated acidic and gneissic rocks. It was after such folding that another period of volcanic activity ensued, and dike after dike of basic material appeared. Whether an overflow of extensive beds of this dike material occurred can not be determined, but the probabilities are negative; nor will it be known whether all these dikes were formed at the same epoch. Observations have not shown any two dikes crossing each other, and this bears strongly against successive epochs of intrusion. Many things point to the probable Keweenaw age of these outbreaks. Whether the Minnesota River Valley dikes be or be not of Keweenaw age, this much at least can be said, the Cambrian rocks of the Northwestern States have not, up to this time, disclosed a single dike of volcanic material. On the other hand, in many places rocks unquestionably of igneous origin have been discovered beneath the horizontal sandstones, shales, and dolomites affirmed by all paleontologists to be of Cambrian age.

MONTEVIDEO DISTRICT.

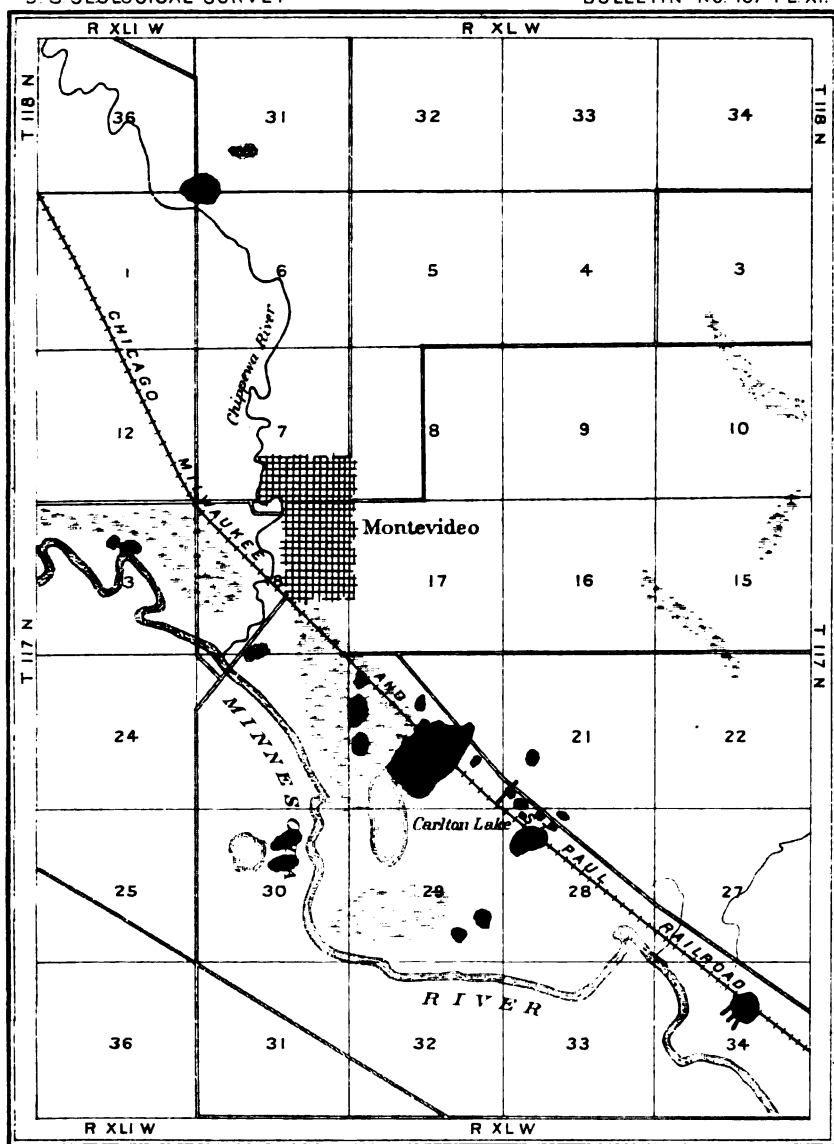
In the western part of Chippewa County there is an area of biotite gneissic rocks of sufficient interest to receive attention. (See Pl. XI.)

At Montevideo the gneiss, which is strongly banded, has a red color. The strike in the vicinity is very nearly NE.-SW., with a uniform dip varying from 30° to 50° SE. The surfaces of the rocks are much waterworn, more even than at Granite Falls. Potholes and irregular grooves are numerous.² One of the potholes is at least 8 feet deep and 3 feet in diameter. Deposits of modified drift surround these worn surfaces. In many places, as at Montevideo, these evidences of water erosion are at a considerable height above the present river, being at least 50 feet at a railway cut near Montevideo, and not less than three-fourths of a mile distant from its channel.

The peculiar kaolinized gneiss, which occurs in many places farther down the river, seems here to have entirely disappeared, the last exposures of such kaolinized gneiss occurring at Granite Falls, at the

¹ The internal relations and taxonomy of the Archean of central Canada, by A. C. Lawson: Bull. Geol. Soc.-America, Vol. I, 1890, p. 178.

² Geology of Swift and Chippewa counties, by Warren Upham: Geol. Nat. Hist. Survey Minnesota, Vol. II, 1888, p. 212.



GEOLOGICAL MAP OF THE MONTEVIDEO DISTRICT

Scale

1 0 1 2 MILES

DIABASE DIKES

GABBRO AND GABBRO-SCHIST

GRANITE AND GNEISS

JULIUS BIEN & CO. LITH. N. Y.

corner of Prentice and Thurse streets, and in a gorge opposite Minnesota Falls, on the north side of the Minnesota River, in the west half of sec. 2, T. 115 N., R. 39 W.

Dikes occur having a NE.-SW. direction, as in the Granite Falls district, which show some interesting phases of composition. Taken as a whole they are not so much altered as at Granite Falls. Some of them are heavily loaded with quartz. Their coarseness varies with their width.

At two or three localities in this district the gabbro-schist rocks appear. One locality is near the line between secs. 18 and 19, T. 117 N., R. 40 W., where the rocks stand in rounded knobs 30 feet or more above the river. There seems to be in this exposure an abnormally large amount of quartz. The presence of this mineral, bearing every evidence of infiltration, is probably the cause of the resistance to erosion shown by these knobs, for the rocks around them have been eroded to a depth which must be considerably below the surface of the

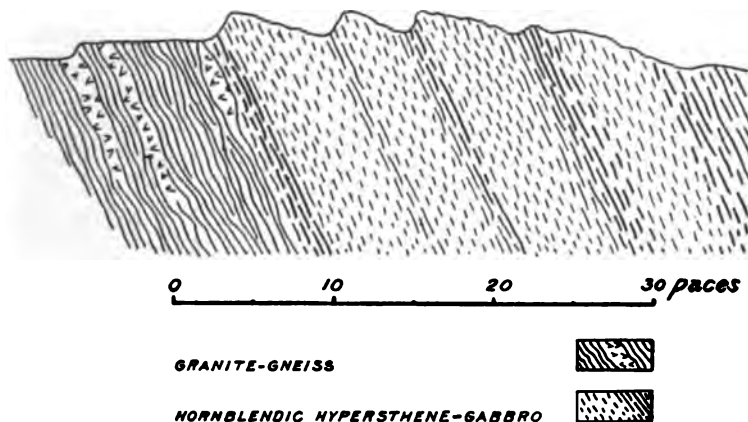


Fig. 6.—Contact of granite-gneiss and hornblende hypersthene-gabbro-schist near Montevideo.

present alluvial beds of the river valley. Another interesting exposure of this type of rock was seen in sec. 31, T. 118 N., R. 40 W., $2\frac{1}{2}$ miles due north from Montevideo.

The area is small, only 60 paces long and 30 paces wide. The rock is dark gray, somewhat imperfectly laminated, and of medium texture. The strike of the laminae is $N. 30^{\circ} E.$, and their dip $55^{\circ} SE.$. The laminae are bent sufficiently to give a wavy appearance, but not enough to make a contorted schist. Indeed, nowhere in the valley have these gabbro-schists exhibited a degree of irregularity in direction of lamination that would entitle them to be called contorted. (See fig. 6.) While the gneisses are contorted in many places, this condition has never been noted where the gabbroids occur in proximity. In mineral composition this rock is a hornblende-hypersthene-gabbro. It is fully described in Chapter V.

LAC QUI PARLE DISTRICT.

For several miles above Montevideo there are few rocks in sight. The bluffs on either side of the Minnesota River slope off in smooth and rounded outlines from the prairie level to the bottoms, a descent of about 100 feet. Lac qui Parle, the "Echo Lake" of the Indians, is simply a broadening of the Minnesota River for several miles of its course, as the result of a dam of silt deposited across the valley by the Lac qui Parle River, which empties into the Minnesota some little distance below the foot of Lac qui Parle. (See Pl. XII.)

The sloping and rounded bluffs on opposite sides of the river are from 1 to 3 miles apart. With the long lake and the meadows between, these bluffs outline a landscape of rare beauty. Along the north side of the lake there is a large tract which is in much of its extent rather swamplike and in times of flood is covered with water. A great portion of it, however, makes highly productive farms. The rocks throughout the valley are mostly covered. The few exposures show a gneiss with distinct lamination, having a strike N. 70° E., with a dip as high as 80° SE. Most of the rock is a hornblende-biotite-gneiss. It is microscopically described in Chapter IV. There are both finely textured and coarsely textured gneisses in this district. The exposures at the lower end of the lake and along its south side seem to be much the finer and lighter colored.

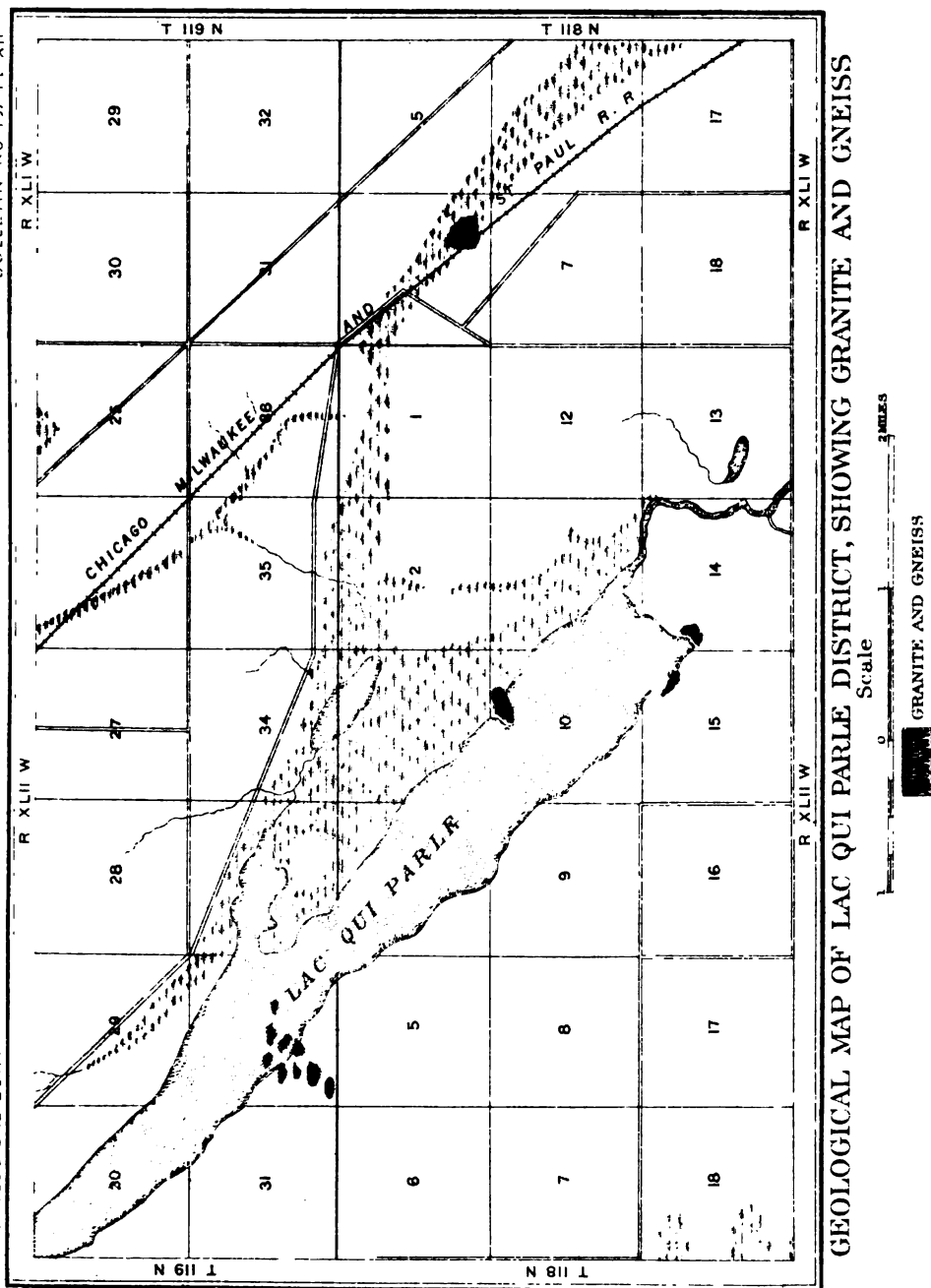
Everywhere the rocks carry an unusual number of veins. These veins are sometimes several feet across, and again almost of paper thinness. In places they are quartz, and elsewhere they are granitic in composition. The quartz veins are seldom of great width, and as a rule are lenticular within the laminae of the inclosing gneiss.

ORTONVILLE DISTRICT.

Passing from Lac qui Parle toward the Odessa district, on the north side of the valley, one finds no exposures between those in sec. 32, T. 119 N., R. 42 W., and those in sec. 20, T. 120 N., R. 44 W. In the Marsh Lake area large masses of gneissic rocks appear on both sides of the river. Their position seems to mark an ancient channel of the glacial River Warren. The large rounded knobs show beautifully glaciated surfaces, with striae nearly parallel with the course of the valley.

In the center of this district (Pl. XIII), along a line extending from sec. 31, T. 121 N., R. 44 W., in a SW. direction through secs. 9 and 15, T. 120 N., R. 45 W., there seems to be an axis of a subordinate anticline; at least to the east of this line the dip of the schistosity is southeasterly, while to the west for several miles there is a northwesterly dip. Within the townships just named there is considerable diversity in the character of the rocks. The larger portion is a hornblende-biotite-gneiss with interlaminated bands of biotitic schist.

In sec. 9, T. 120 N., R. 45 W., there stand two or three knobs of a bio-



GEOLOGICAL MAP OF LAC QUI PARLE DISTRICT, SHOWING GRANITE AND GNEISS

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titic quartz-pyroxene-schist. So far as mineral constituents are concerned, this rock is very similar to the gabbroid schists from the several localities in the valley already mentioned.

We have here, as well as in the districts already described, rocks which for convenience have been termed "squeezed eruptives" by the lithologists who have studied them for other regions. Large areas of rocks, possibly spread out as flows of igneous matter, together with rocks of different chemical and mineral composition, were squeezed in the continental movements subsequent to their extrusion to such an extent that a schistose structure was induced. Subsequent conditions have no doubt played their part in bringing these rocks to their present mineralogical and structural states.¹ The fine crumpling so often seen in this structure is absent in the schistose rocks of the Minnesota River Valley.

In the old gorge of the River Warren, in secs. 9, 15, and 16, T. 120 N., R. 45 W., around the mouth of the Yellowbank, a small creek

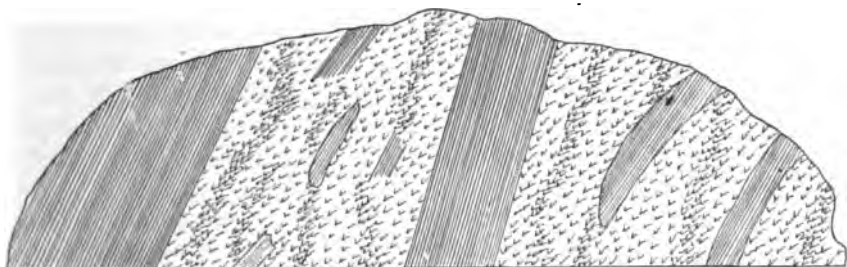


FIG. 7.—Exposure of granite-gneiss and hornblende-biotite-schist, showing alternation of the two rock species, sec. 15, 1,200 paces N., 1,600 paces W., T. 120 N., R. 45 W., Minnesota.

which enters the Minnesota River near this place, are some interesting alternations of gneiss and biotite-schist, though so small a part of the rocks of this locality is in sight that only occasional glimpses of them could be gained. The two types of rock are interlaminated, sometimes in belts several feet in width and sometimes in bands less than an inch wide; while lenticular inclusions of the schists in the gneiss are frequently to be seen. Fig. 7 shows this relation. Here and there a pegmatitic condition of the more feldspathic gneissic portions stands out in sharp contrast with the bordering schistose belts.

The gneissic condition is evidenced, not in the ordinary lamination presented by alternating biotitic and feldspathic bands, which as a rule characterize the gneisses of this valley, but in the prevailing direction of the large and porphyritic feldspar crystals.

Around Odessa are several gneissic exposures of interest. To the east, where the Chicago, Milwaukee and St. Paul Railway comes down from the prairie around Appleton and Correll to the river bottoms, which it follows from Odessa to Ortonville and Bigstone, the gneisses outcrop in fresh, firm masses.

¹ Geology, Chemical, Physical, and Stratigraphical, by Joseph Prestwich, Vol. I, 1888, p. 270.

In sec. 31, T. 121 N., R. 44 W., 700 paces N., 1,350 paces W., within a few paces of milepost 168 of the railroad, a porphyritic granite and gneiss appear, with inclusions of schist. The main mass of the exposure is gneiss; in places it is granitic. The feldspar crystals are frequently $1\frac{1}{2}$ inches in length. Their color is a light pink, and they abound in inclusions of quartz and even of other feldspars. Sulphide of iron is so abundant that almost every fresh fracture discloses it. The species is presumed to be marcasite, since it readily decomposes on exposure to the air and covers the rock surfaces with an iron rust. The schist inclusions exhibit a fine-grained dark-colored hornblende-biotite rock with secondary fine-grained quartz and several feldspars.

Only 300 paces from milepost 169, in sec. 36, T. 121 N., R. 45 W., is another set of exposures showing similar types of rock. A distinct gneissic structure prevails, the lamination running N. 20° E., with a SE. dip. Schistose inclusions abound. In this respect these exposures are essentially the same as the large boulder mentioned by Upham, and referred to on the next page.

In the low, swampy area along the river, south of the knobs just located, are many outcrops of gneissic rock almost identical with those near the railroad, just noted. In places a sharp lamination is seen, and again the rock becomes so granitic that it is only in the parallel position of the feldspar individuals that any gneissic structure is disclosed.

A short distance west of the station at Odessa several small knobs occur, different in no essential particular from the gneiss and granite near mileposts 168 and 169, above mentioned. The word "granitoid" well describes the texture. The strike of the masses is nearly N.-S., and the dip is 40° - 45° E. The rock as a whole is not in so good a state of preservation as that nearer the river—a fact very commonly noted in rocks lying along river courses.

Within the 3 miles of the valley immediately below Ortonville there are many large areas of a granitoid gneiss. The rocks generally dip toward the northwest at a high angle. This gneiss has a prevailing red color (see Pl. XVI, A), varying at times to gray through the increase in the quantity of biotite and hornblende. The feldspar crystals are frequently large. Below the railway station at Odessa are two or three glacial moraines which carry an enormous amount of granitic and schistose material. Boulders of these rock types constitute a large portion of the material in many places. The proportion of the crystalline rocks in this glacial débris is evidence of enormous glacial erosion of the Archean rocks lying in the region stretching northward and northeastward from the Minnesota River. Warren Upham mentions this accumulation of boulders,¹ and explains it as a morainic plain whose material, accumulated in an early epoch of the great Ice age, was partly buried beneath the débris of subsequent southeast-

¹Geology of Bigstone and Lac qui Parle counties, by Warren Upham: Geol. Nat. Hist. Survey Minnesota, Vol. I, 1884, p. 626.



GRANITE QUARRY AT ORTONVILLE.

ward extensions of the ice. The surface of this plain stands 50 to 75 feet above the river and 50 feet below the top of the bluffs, or the general prairie level. The bowlders composing this *débris* are quite large in places. Upham mentions one 30 feet or more in diameter, and another, of gray granite, measuring 20 feet, "in which are seen at one side several fragments of hornblende-schist up to 3 and 4 feet in diameter."¹ The writer and his assistant, Mr. J. E. Manchester, took a mid-day lunch in the shade of a bowlder of granitoid gneiss lying near the bluff on the south side of sec. 11, T. 120 N., R. 45 W., which measured 15 feet in height, 34 feet in width, and 43 feet in length. Its weight was estimated to be over 100 tons.

In this mass of glacial drift there is much fine material, apparently to some extent calcareous, intermingled with occasional calcareous bowlders. Most of this calcareous material has, no doubt, been torn from the Minnesota shales and limestones of Cretaceous age.

The surfaces of the granitoid gneisses immediately below Ortonville are well worn and rounded by glacial erosion. Indeed, no better exhibition of the *roches moutonnées* of glaciated districts can be seen in the whole valley. Any unevenness in the hardness of the rock is clearly indicated by the grooves and protuberances on the surface. The direction which the ice took down the Minnesota River Valley was almost the course of the present stream. There is no doubt that the River Warren occupied the same course. The grooves and *striae* which indicate this direction can be distinctly seen on the surface of almost every rock within the first 3 miles below Ortonville, and also in the old river channel now in part occupied by the unruly and tortuous stream, Yellowbank Creek, which empties into the Minnesota River on the south side of sec. 34, T. 121 N., R. 45 W.

To the southwest of Ortonville, in sec. 16, T. 121 N., R. 46 W., stands a considerable mass of granitic gneiss, which is the most westerly exposure of this rock now known in this valley. Indeed, this is the last granitic outcrop in the whole Northwest until the great uplift of the Black Hills of South Dakota is reached. Deep wells bored in several South Dakota towns to the west and southwest show these rocks at from 50 to 100 feet below the surface. Millbank, 10 miles west of the Minnesota State line, has bored several wells with that result.

REDWOOD RIVER VALLEY DISTRICT.

Having passed in brief review the most notable rock exposures of the valley as they lie bounded on either side by the sharp ridges of morainic material, we will now note the few outcrops of crystalline rocks known to stand upon the prairies to the south and west of the Minnesota River and north of the quartzites which are probably continuous from Courtland to Pipestone. The gorge of the Redwood River from the south border of the Minnesota River bottoms into the

¹Geology of Bigstone and Lac qui Parle counties, by Warren Upham; Geol. Nat. Hist. Survey Minnesota, Vol. I, 1884, p. 626.

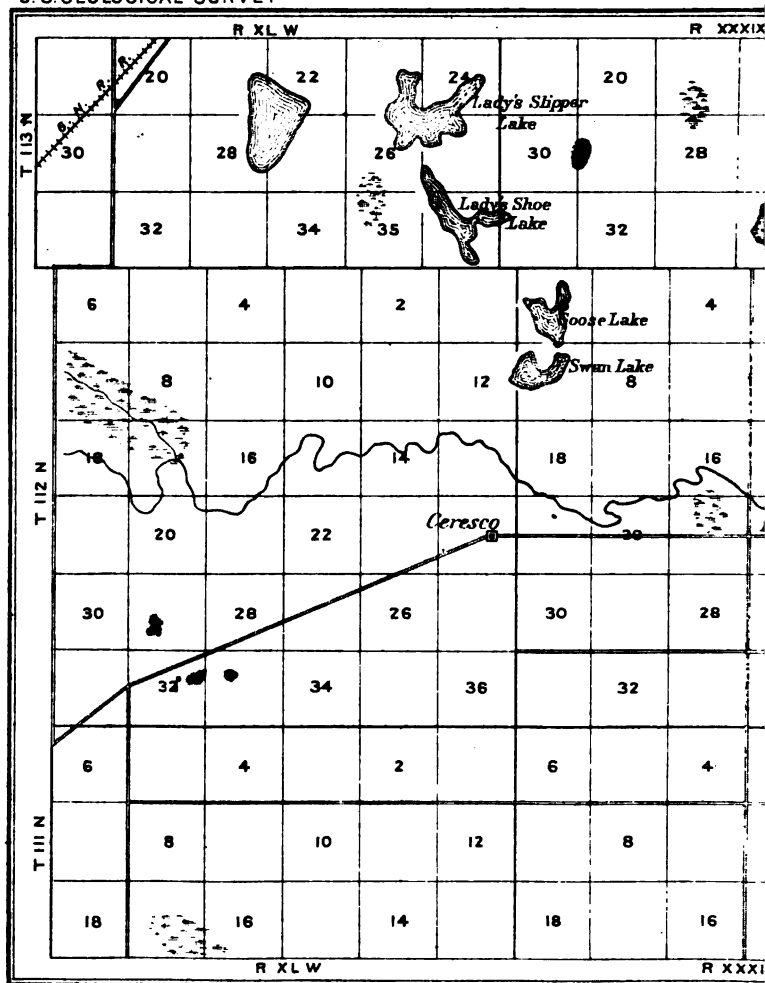
middle of the city of Redwood Falls is one of great natural beauty and interest. The rock is a gneiss, so altered in places that it has become an impure kaolin, sometimes green and sometimes red. From that completely changed condition to one of a fresh and tolerably firm building stone there is a well-graded series. Cretaceous beds overlie these gneisses in places. The length of the gorge must be at least 2 miles, although the air-line distance is considerably less. At the head of this gorge is a cascade 25 or more feet in height. (See Pl. VII.) The rock here is much fresher than at points farther down the stream. Above this principal cascade are several rapids where the water tumbles over floors of gneiss. Beyond, a few hundred paces, no rocks appear, save occasional boulders, until miles of the slowly ascending prairie have been traversed.

Beyond the falls of the Redwood River in the city of Redwood Falls one loses sight of all rocks, the bed of the Redwood River resting upon the glacial till of the prairies. Artesian and deep wells sunk in Redwood Falls and several places on the prairie to the west, whenever deep enough, pass entirely through the glacial drift and all other fragmental deposits and disclose the gneissic rocks, which lie at depths varying from a few feet to 300 or 400 feet. So it may be positively maintained that gneissic rocks underlie the whole district. In three or four townships south of the river small areas of gneiss are seen at the surface (Pl. XV). These are all areas of a distinctly laminated, very quartzose, hornblendic, and biotitic gneiss, in places considerably contorted. Their surfaces are unusually well preserved. They must stand from 1,050 to 1,200 feet above the sea, and thus between 200 and 350 feet above Bigstone Lake, which is practically the head of the valley. Where the covering of glacial débris has been but recently removed, beautifully polished surfaces are disclosed. In sec. 32, T. 113 N., R. 38 W., the glacial striae show a direction S. 65° E.

POST-CAMBRIAN DEPOSITS.

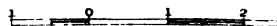
In the Morton and Beaver Falls districts (Pls. V and VI) there are several exposures of supposed Cretaceous sandstones and shales. Along the Minneapolis and St. Louis Railroad, from the prairie town of Franklin down to the river bottoms at Morton, several cuts have been made in a medium-grained white sandstone. Beside the wagon road between the Franklin station and the bottoms in sec. 10, T. 113 N., R. 35 W., in the bluffs, where the glacial débris has been removed in the construction of the highway, there are exposures of a white sandstone. Again, in the gorge of Birch Cooley Creek, on the line between secs. 32 and 33, and also just above the old mill in sec. 28, all in T. 113 N., R. 34 W., are exposures of horizontal, well-bedded white sandstone of medium grain and slight induration. These exposures are undoubtedly a continuation of the same beds that are seen along the railroad at the same and somewhat lower altitudes. The exact thickness of

U.S. GEOLOGICAL SURVEY



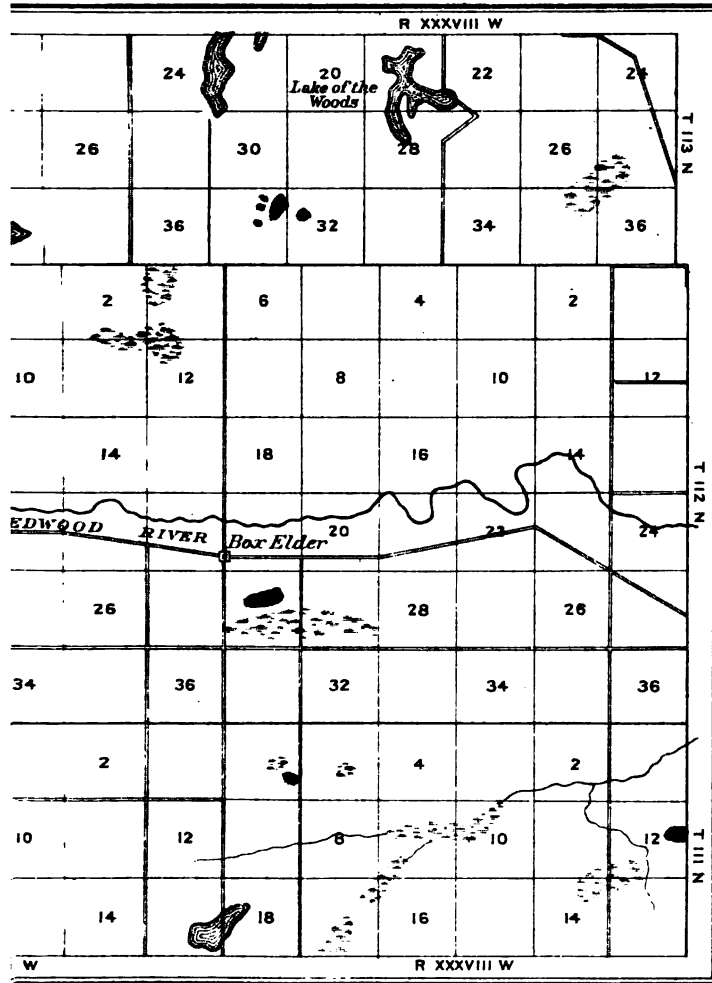
GEOLOGICAL MAP OF THE REDWOOD RIVER I

Scale



GRANITE

JULIUS BIE



DISTRICT, SHOWING GRANITE AND GNEISS

0 3 4 5 MILES

AND GNEISS

1920 U.S. N.Y.

this sandstone can not be stated, but nowhere is an exposure more than 12 or 15 feet thick.

In sec. 5, or vicinity, T. 112 N., R. 34 W., there is reported "an exposure of sandy marl, horizontally stratified, seen in the road that descends from the Lower Sioux Agency to the ferry [across the Minnesota River]."¹ Along Crow Creek shales appear, and along the Redwood River both shales and seams of lignite occur.² These Cretaceous rocks are not well compacted. The exposures stand at some little height above the river, and appear to rest in protected spots where the higher gneissic bluff protected them from glacial erosion. This rock was first observed by Keating,³ who mentions a fine white sandstone as forming the bluffs at a place corresponding to this portion of the valley. "In the sandstone exposures I saw no fossils, nor were other facts observed which could bear on geological age." Geographical situation and lithological characters naturally assign them a place with the beds along the Cottonwood River, already mentioned in the discussion of the New Ulm area in the Cretaceous.⁴

The lignites have at various times excited considerable local interest, but all efforts at profitable working have been thus far in vain.⁵ No systematic exploration has yet been done to determine the economic value of the deposits or to work out the fauna or flora.

Between the quartzite exposure near Redstone and the "basal conglomerate" of sec. 27, T. 110 N., R. 30 W., and near the line between secs. 27 and 32, there is a bed, apparently thin, of poorly compacted limestone intermingled with shales and sand. On the south side of the Minnesota River, in a terrace stretching to the southeast nearly parallel with the river, is another deposit of the same lithological character. No doubt the two deposits are portions of the same bed, which has been cut in two by the Minnesota River. The present existence of this limestone is doubtless due to the protection afforded by the quartzite bluffs to the north and east, which stand considerably higher than any limestone exposures observed. The rock is used for making lime at several kilns. As taken from the quarries its appearance is peculiar. It occurs in corroded and vesicular blocks and in crystalline masses. The color of these masses on freshly fractured surfaces is seldom uniform, but varies from white to brown. It does not appear to be an extensive formation, either in thickness or in area.

Along the Big Cottonwood River, to the west of the exposures named, and probably separated from them by river and glacial erosion, are beds of sandstone. They are horizontal, fairly well bedded, unevenly

¹ Geol. Nat. Hist. Survey Minnesota, Vol. I, 1884, p. 577.

² Compare The geology of the Minnesota Valley, by N. H. Winchell; Geol. Nat. Hist. Survey Minnesota, 1873, pp. 187, 188; also Warren Upham, Final Rept., Vol. I, 1883, p. 572, et seq.

³ Narrative of an Expedition to the Sources of the St. Peter's River, Lake Winnepeck, Lake of the Woods, etc., by William H. Keating, London, Vol. I, 1825, p. 362.

⁴ Ante p. 21.

⁵ Geology of Brown and Redwood counties, by Warren Upham; Geol. Nat. Hist. Survey Minnesota, Vol. I, 1884, p. 577.

textured, and generally white in color, although some of the layers are brown, particularly in the center of the exposed beds of the river gorge in sec. 36, T. 110 N., R. 31 W. At this location, in the lenticular layers of sandstone on the north side of the river, where a shady condition is favorable for their preservation, many fossil leaves have been found. These are *Populites elegans* Lesq., *P. litigosus* Lesq., *Ficus austiniana* Lesq., *Magnolia alternans* Heer, *Protophyllum credneroides* Lesq., *P. intergerrimum* Lesq., and *Laurus plutonia* Heer, indicating that the rocks are of the Dakota formation of the Cretaceous.¹

In general the data regarding the stratigraphy of western Minnesota, accumulated through the records of deep wells, go to show that a large portion of this district has a series of Cretaceous beds sandwiched between the drift deposits and the Paleozoic and pre-Paleozoic formations, which extend under ground westward from the central and eastern portions of the State. These Cretaceous beds are not at present of great thickness, nor are they of uniform composition and succession, as is shown by a comparison of borings from different localities. This area, being doubtless on the eastern border of the great Cretaceous gulf, could never have received the enormous sedimentation which accumulated through the western portion of the Dakotas and southward. The present thickness of the Cretaceous and of the drift accumulations together represents at most only a few hundred feet of sediments. Owing to their soft character, these partially compacted deposits easily yielded to the abrasive action of Glacial time. It can easily be noted by the geologist crossing Minnesota from east to west that the character of the drift debris gradually undergoes a change. In the east it is predominantly siliceous. The pebbles are chiefly from the great terranes of the pre-Cambrian series, and where calcareous pebbles occur they seem to be wrought out of the Cambrian and overlying formations of the Paleozoic, their fossils proving their age.² Water in the streams is somewhat hard, yet not objectionably so. In the west a fine calcareous shale, seldom appearing in large bowlders, gives a different texture to both the till and the modified drift. The color of the morainic material is different. Water from its springs is hard and far from pleasant for domestic use. Near Ortonville are springs which yield sufficient quantities of the carbonates of calcium and magnesium to deposit considerable masses of travertine. Travertine deposits are not infrequent in the upper portion of the valley. Magnesium salts and other compounds are usually seen in dry weather as efflorescences covering low grounds and desiccated sloughs throughout western Minnesota.

North of the Ortonville district Paleozoic limestones and fossils constitute a considerable portion of the drift material. At Morris and

¹ Geology of Brown and Redwood counties, by Warren Upham; Geol. Nat. Hist. Survey Minnesota, Vol. I, 1884, p. 573. See, also, Cretaceous fossil plants from Minnesota, by Leo Lesquereux; Geol. Nat. Hist. Survey Minnesota, Vol. III, Pt. 1, 1895, pp. 1-22.

² Paleozoic fossils in the drift, by F. W. Sardeson; Bull. Minn. Acad. Nat. Sci., Vol. III, 1891, p. 317.

at Fergus Falls large numbers of fossils have been found and identified as Silurian and Devonian species. These formations underlie and are more resistant than the Cretaceous, and hence they must be referred to a subordinate place in our search for the source of the material of the glacial deposits. Since the Cretaceous is presumed still to remain over much of the area, the Paleozoic may also be presumed still to remain beneath it. Upham is confident that it does,¹ and that the bowlders we find represent the disruption of its edges only. Suffice it to say that throughout the entire valley above Courtland no exposures of Paleozoic rocks were seen, and no Cretaceous rocks were noted in place above Redwood Falls.

While the glacial striæ seen on the rocks have been noted from time to time in this geographical sketch, the following table may be found convenient as containing all the observations made in the explorations of the valley by the writer and others, so far as their observations are at hand. The writer is the authority unless another name is given. Starting at Bigstone Lake, the order is down the valley:

Glacial striæ observed in the Minnesota River Valley.

Locality.	Direction.
Sec. 15, T. 121 N., R. 46 W	S. 40° E.
Sec. 21, T. 121 N., R. 46 W	S. 40° E.
Sec. 22, T. 121 N., R. 46 W	S. 40° E.
NE. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 26, T. 121 N., R. 46 W	S. 35° E.
Bigstone Lake	SE.
NE. $\frac{1}{4}$ sec. 12, T. 120 N., R. 45 W	S. 45° E.
NW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 16, T. 120 N., R. 45 W	S. 30° E.
SE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 22, T. 120 N., R. 45 W	S. 40° E.
NW. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 22, T. 120 N., R. 45 W	S. 40° E.
SW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 14, T. 118 N., R. 42 W	S. 45° E.
East Granite Falls	S. 45°-50° E. (Upham.)
NE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 4, T. 115 N., R. 39 W	S. 50° E.
N. $\frac{1}{4}$ sec. 11, T. 115 N., R. 39 W	S. 50° E.
NW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 29, T. 113 N., R. 38 W	S. 52° E.
Posen, T. 113 N., R. 39 W	S. 50° E. (Upham.)
Echo, T. 113 N., R. 38 W	S. 50°-55° E. (Upham.)
NE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 32, T. 113 N., R. 38 W	S. 53° E.
NW. $\frac{1}{4}$ sec. 10, T. 113 N., R. 35 W	S. 60° E. (Upham.)
Beaver Falls	S. 60° E. (Upham.)
NW. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 30, T. 112 N., R. 38 W	S. 61° E.
NE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 6, T. 111 N., R. 38 W	S. 55° E.
SE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 12, T. 111 N., R. 38 W	S. 63° E.
E $\frac{1}{4}$ sec. 12, T. 111 N., R. 38 W	S. 50°-60° E. (Upham.)
SW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 1, T. 111 N., R. 32 W	S. 48° E.
Ridgely Township	S. 60° E. (Upham.)
NE. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 35, T. 110 N., R. 30 W	S. 33° E.

¹Geology of Ottertail County, by Warren Upham: Geol. Nat. Hist. Survey Minnesota, Vol. II, 1888, p. 543.

CHAPTER IV.

GNEISSES.

GENERAL CONSIDERATIONS.

The laminated granitic rocks designated gneisses constitute the great bulk of the crystalline rocks stretching along the bottoms of the Minnesota River Valley between New Ulm and Ortonville and standing in a few isolated knobs in the higher prairie district south and west of the river.

As a rock type, gneiss probably presents more varieties than any other known species. In addition to all the chemical and mineral phases which the granites are known to possess, the gneisses exhibit all the modifications which the lamination of a rock may develop. Structurally a series is recognized from the granitoid masses where only the imagination of the geologist or his observations covering extensive rock areas can distinguish between a gneiss and a granite, to that other extreme where the discrimination between a gneiss and a schist is based on equally uncertain data. As Hager truly says in discussing the granites and gneisses of Vermont: "Cases occasionally occur when it is very difficult to decide whether the rock be stratified or not. Even those rocks which all geologists concede to be granites . . . evince such a disposition to split in certain directions that the workmen generally regard them as stratified rocks."¹

There is scarcely a step in the structural series of gneissic rocks that is not represented by the gneisses of this valley. The granite-gneisses of Ortonville, Yellowbank, and Fort Ridgely, the porphyroidal exposures of Beaver Falls and Odessa, the normal and strongly banded masses at Morton, the schistose bands of many other localities, as along the lake shore below Vicksburg (sec. 29, T. 114 N., R. 36 W.), all express certain well-known phases of this rock type.

Some exposures are intricately contorted and others evenly banded. The rocks of some localities are shattered throughout, and in other localities there are immense areas where for long distances no fault or joint is seen.

In mineral composition there is even greater diversity than in structure. In the valley are hornblende-gneiss, hornblende-biotite-gneiss, augite-biotite-gneiss, biotite-gneiss, and biotite-muscovite-gneiss, with every possible transition stage between them. The chemical composition varies from a highly siliceous to a basic gneiss.

¹ *Economical geology of Vermont*, by A. D. Hager: *Geology of Vermont*, 1881, Vol. II, Pt. IX, p. 736.

In using the term "gneiss" to cover rocks with so great a range of structural and mineral characters, it will at once be seen that its application must be much wider than that given it in the early days of geology. Excluding those dioritic and gabbroid rocks which are sometimes regarded as gneisses,¹ there remains the vast series of laminated rocks consisting of feldspar of several species—without exception more than one is present—quartz in one and two generations, the micas or hornblende, or both, and occasionally some other representative of the bisilicate constituents.

The investigations made by the writer show the gneisses of the Minnesota River Valley to be peculiar. They differ from the gneisses of the Muhl circuit, since in that district muscovite predominates in one division and biotite in the other;² from the Korean gneisses, which, according to Roth, are to a great extent biotitic and associated with hornblende and other schists;³ from the pyroxene gneisses of Varberg, which Törnebohm recently described;⁴ from those of Scotland, described particularly in their relation to the attending granite by J. J. H. Teall;⁵ from the varieties of Vermont gneisses enumerated by Hitchcock;⁶ from the gneisses of New Hampshire described by Hawes,⁷ and from the hornblendic gneisses of the Farmington Canyon mentioned by King.⁸

The geologic age of the rocks under discussion can only be assumed. The fact that they are geographically isolated from every other district where similar crystalline rocks occur has already been emphasized. The glacial drift everywhere spread over them conceals their relations to the hornblende-biotite-granites of the Sauk River Valley to the northeast, and to the epidote-granites of Ashley and Ward to the north. Their stratigraphic relation to the quartzites of Courtland and southwestern Minnesota has already been pointed out. Cretaceous limestones around New Ulm, and sandstones and shales below Redwood Falls, in the Birch Cooley Gorge, and toward Franklin, lie close to them, if not immediately upon them. They are believed to represent a portion of the vast stretches of Archean rock formations underlying Minnesota and the neighboring States of Wisconsin, Iowa, and the two Dakotas.

By means of artesian-well borings made in many portions of the States named, the crystalline rocks have been discovered and their

¹ British Petrography, by J. J. H. Teall, London, 1888, p. 295.

² Materialien zur Orographie und Geognosie des Muhlviertels, Referat, by Hans Commender: Neues Jahrbuch für Mineral., Bronhard, Vol. I, 1885, p. 417.

³ Beiträge zur Petrographie von Korea, by J. Roth: Rept. in Neues Jahrbuch für Mineral., Bronhard, Vol. II, 1887, p. 104.

⁴ Naagra exempel paa pyroxenförande graniter och gneisser, by Törnebohm: Referat, Neues Jahrbuch für Mineral., Bronhard, Vol. I, 1881, p. 70.

⁵ British Petrography, London, 1888, p. 326.

⁶ Azotic rocks, by C. H. Hitchcock: Geol. of Vermont, Vol. I, Pt. III, 1861, p. 454.

⁷ Mineralogy and lithology, by Geo. W. Hawes: Geol. of New Hampshire, Vol. III, Pt. IV, 1878, p. 209.

⁸ Systematic geology, by Clarence King: U. S. Geol. Expl. Fortieth Par., Vol. I, Chap. II, Archean, p. 51.

depth from the surface has been measured. In this way it has been found that the Paleozoic rocks of Wisconsin and Iowa form only a thin sheet, from a few feet to a few hundred feet thick, over the pre-Paleozoic rocks beneath. In the Dakotas on the west the gneisses and quartzites slope gradually westward from near the west line of Minnesota beneath the water-bearing Cretaceous sandstones, with their overlying shales, until at the James River Valley at Aberdeen, South Dakota, they are 1,220 feet below the surface. Toward the north also, at Moorhead and at Fargo, granitic rocks are reached at 375 feet. The slope toward the south, beneath the Paleozoics of Wisconsin and Iowa, is shown in a similar manner to be a gradual one. Granitic rocks are reached at 524 feet beneath the city of La Crosse, and quartzite is said to be reached at 768 feet beneath the surface at Spencer, Iowa, while to the east and northeast surface exposures are soon reached in Wisconsin. With such a comparatively extended plain on which the Paleozoic sandstones and limestones were laid down, the formation and deposition of this sediment must have been a process of vast time extent, and it is only natural to find the floor of fresh rock distinguished by very marked irregularities after the scorings of the successive ice invasions.

There is no reason to believe that in any geologic period since Cambrian time there has been any marked or unequal uplifting of this region, but as a vast, central continental plain it has been subject to the ordinary oscillations of level illustrated by those of the Glacial epoch. It is believed that nowhere in the States named—save, perhaps, for a part of the area of the Dakotas and a portion of the Mississippi Valley—does the upper limit of the Archean rocks sink below the present level of the sea.

The metamorphosed condition of the rocks points to an enormous time gap between the close of their building processes and the first deposition of Cambrian sediments on this part of the North American continent. Walcott has placed these first sediments in the Upper Cambrian,¹ while Hall and Sardeson refer them to the Middle Cambrian.²

Nowhere have any indications been found that the crystalline rocks can be regarded as altered sedimentary strata, as was recently announced by Director-General Geikie for some of the gneisses of the northeast Highlands of Scotland.³

The considerations above given, together with the mineral composition and other lithological characters, lead the writer to the opinion that the ancient gneisses under discussion must be regarded as of Archean age. Indeed, no geologist has thus far placed them in any other division of geological time. Owen, who calls these "the crystal-

¹ Fauna of the Lower Cambrian or Olenellus zone, by C. D. Walcott: Tenth Ann. Rept. U. S. Geol. Survey, 1890, p. 548.

² Magnesian series of the Northwestern States, by C. W. Hall and F. W. Sardeson: Bull. Geol. Soc. America, Vol. VI, 1895, p. 170.

³ Nature, Vol. XLIV, 1891, p. 480.

line and metamorphic rocks," Anderson and Clark, who designate them "the primitive system of rocks," and others, down to Van Hise,¹ place the Minnesota River Valley rocks in the bottom division of the geological series. The term "crystalline and metamorphic rocks" of Owen and the "primitive system" of Anderson and Clark meant the same thing as does the word Archean, first proposed to geologists by Dana in 1874 in his subdivisions of geological time.²

The subdivision of these rocks into series of greater or less independence and importance can be made without much difficulty. In traversing them across their strike, as one must in ascending or descending the valley, many modifications of the gneissic type are encountered. These modifications lie partly in the structural phases which have already been pointed out and partly in the lithological characters which are now to be discussed.

Our studies will lead us to the conclusion that we have had under investigation two series of rocks, the one exposed at the two ends of the valley, typified in the exposures at and around old Fort Ridgely and at Ortonville, and the other in the central part, at Granite Falls and at Minnesota Falls. The Granite Falls series is represented by the gneissic exposures in Delhi and neighboring townships (Pl. VIII) and along the bottoms to a point several miles above Granite Falls, in sec. 14, T. 116 N., R. 40 W. (Pl. X). The Ortonville series is represented by the heavy and generally granitoid exposures seen stretching northwesterly from New Ulm to the great rock barrens, reaching into secs. 12 and 13, T. 114 N., R. 38 W. (Pls. IV, V, VI, VII, and VIII). Again, in the river bottoms below Montevideo the same series reappears and continues uninterruptedly to Ortonville (Pls. XI, XII, and XIII). Exposures of the granite-gneisses cover several square miles below the latter place. Their extent and favorable condition for study suggested the name Ortonville that has been applied to the series so extensively developed in the valley. Nowhere do these rocks rest in contact with those appearing in massive exposures around Fort Ridgely, Morton, Beaver Falls, and Montevideo.

In the study of the rock succession represented in the valley, the rock phases will be described according to the petrographical characters. Such a classification will be found exceedingly simple and at the same time progressive. Starting with the massive or granitoid types, the discussion will follow to the schistose and semibasic varieties.

MINERAL CONSTITUENTS OF THE VARIOUS GNEISSES.

Primary quartz.—In many typical hand specimens of the hornblende-biotite-gneisses quartz is the most conspicuous mineral among the constituents. This is noticeably the case in the granitoid gneiss localities.

¹An attempt to harmonize some apparently conflicting views of Lake Superior stratigraphy, by C. R. Van Hise: *Am. Jour. Sci.*, 8d series, Vol. XLI, 1891, pp. 117-137.

²*Manual of Geology*, by J. D. Dana, 2d ed., 1874, p. 139.

In places among these rocks quartz seems to constitute at least two-fifths of the whole bulk (sp. 5268, 5342). Again, there are isolated areas where the quartz occurs in lenticular masses almost wholly unmingled with other minerals. Typical localities are at Hindarmann's farm (sp. 5183), a mile or so above old Fort Ridgely (sp. 5184 A), near the mouth of Birch Cooley (sp. 5208), and at other places. These occurrences will be discussed in another place under vein material. The usual mode of occurrence of quartz, however, obtains here—that is, as interstitial material generally distributed among the other constituents.

Frequently there lie along the sides of fractures zones of quartz containing cavities, usually filled with liquid but sometimes empty. The origin of the quartz by pressure is thus indicated. As a rule the cavities are in clusters or bands. The quartz is broken up into numerous interlocking individuals, some of which are of large size. The liquid-filled cavities often occur in streams crossing both the quartzes and the adjoining feldspars until they lie scattered across the entire slide (sp. 5237, 5301, 5308, 5344, and others).

Very generally, too, in these primary quartz areas there are numerous inclusions of minute, needle-shaped crystals, which lie in every possible direction, and are too small to be studied with any positive results. They are believed to be rutile needles, both from kindred observations in other localities and from the fact that Prof. James A. Dodge, of the University of Minnesota, made a very careful qualitative examination of some of this quartz from Hindarmann's place (sp. 5183, 1,750 paces N., 1,750 paces W., sec. 22, T. 111 N., R. 32 W.) and discovered in it distinct traces of TiO_2 .

In many places throughout the valley, particularly around Fort Ridgely and Ortonville, the quartz has a remarkably opalescent, bluish aspect, giving a peculiar skimmed-milk appearance to the mineral. The quartz is white, and at the same time has a watery, limped look not usual in milky quartz. Occasionally an amethystine tint is also present. The opalescence is seen in the gneissic quartz and in the vein-like segregations alike. Where there is the highest degree of opalescence the needle-shaped crystals mentioned are most abundant. The conclusion was therefore drawn that the opalescent character depends on the abundance of the mineral rutile within the quartz.

Such inclusions in the quartz as have been pointed out occur only in those large yet allotriomorphic individuals with which all the gneisses of the valley abound. The individuals, usually regarded as primary, may or may not be one of the original mineral constituents of the rock. Their existence and present condition afford no evidence touching the origin or development of quartz as an essential constituent mineral. The quartz might have been present at the original crystallization of the rock or it might not have been. Time and the alteration processes to which the rocks have been subjected might have developed large and numerous areas of this mineral as it has of others.

Secondary quartz.—In addition to the large areas of quartz just noted there are almost always present segregated areas of a finely crystalline phase of this mineral. These areas are at times around the borders of the feldspars, again, in the midst of the feldspars themselves, especially within the orthoclase and microcline individuals, and at other times in the areas of altered basic constituents intermingled with the hornblende, biotite, magnetite, etc., which have resulted from the breaking up of the original mineral constituents of the rock. In these areas the quartz exists in very minute individuals, highly transparent, and, under crossed nicols, brightly polarizing. They are sutured together, and are exceedingly free from impurities of every kind.

Three forms of secondary quartz are noticeable:

1. Fine, granular segregations, perfectly transparent, compact, and almost wholly free from impurities.
2. Fine, brightly polarizing, isolated granules and pegmatitic areas in the midst of and around the feldspars. They occur more frequently associated with the potash feldspars, i. e., orthoclase and microcline, than elsewhere, although they are frequent in individuals of the albite type.
3. Vermicular quartz in and around the feldspathic individuals, more particularly those which show strong evidences of alteration.

Of peculiar interest in these granitoid rocks is this vermicular quartz, which is very widely distributed. As a rule it is microscopic, very rarely appearing in areas sufficiently large to be detected with the unaided eye. Almost without exception its secondary origin is evidenced by its distribution, for it is found within the boundaries of the older rock constituents, particularly the feldspars.¹ Within this group of minerals no particular preference seems to be shown; it as frequently invades orthoclase or microcline as it does the plagioclastic species. The contorted, vermicular passages through which the silica has made its way into the corroded constituents can be seen on Pl. XVIII, *B*, taken from the hornblende-biotite-gneiss (sp. 5396) of sec. 30, T. 112 N., R. 38 W., the town of Vesta, in the prairie region of western Redwood County.

Feldspars.—This mineral group is represented by several members. There is no apparent law of occurrence; scarcely a sample was taken that did not show several species. In few places did the rock show any single species as especially predominant.

In size of individuals there is the greatest diversity, the apparently primary ones reaching in places the size of several inches, while others are very small. The former are usually filled with the products of their own decomposition, mingled with and modified by those of the other mineral constituents of the rock. The outlines of the individuals "of primary consolidation," as Fouqué and Lévy call them,² are seldom

¹ *Minéralogie Micrographique*, by Fouqué et Lévy, Paris, 1879, p. 193.

² *Op. cit.*, p. 151.

clearly defined. They usually merge into a mingled mass of quartz and feldspar individuals or into a zone of quartz alone.

At a few places in the valley—for instance, around Ortonville—orthoclase seems to have suffered alteration more than any other feldspathic constituent. Yet amid all the changes it has undergone this mineral has not completely lost its identity.

Microcline plays a very important part in the constitution of these gneisses. It is frequently in porphyritic crystals an inch or more long. The surface usually has a pale reddish tint, and the fine fractures are coated with limonite. In point of quantity microcline seems greatly to exceed orthoclase in this group of gneisses.

While orthoclase and the plagioclases are, as a rule, more or less altered to kaolin, muscovite, and other products, with few exceptions the microcline areas are fresh and transparent. In this respect these rocks are no exception to the condition observed in northern Michigan. Where the microcline has altered to a perceptible extent it contains many small areas of clear quartz. These areas are either closely compacted or in the vermicular forms.¹ Wherever the feldspars are secondary—and such places are numerous—microcline takes the foremost place in quantity as well as in the development of its characteristic features.

In its distribution microcline accompanies both orthoclase and the acid plagioclases. Usually the boundaries of the contiguous individuals are sharply defined, yet not infrequently the sharp definition disappears and the line of demarkation can not be seen. Such a merging of an oligoclasic individual with microcline is seen in Pl. XIX, *B*, from a specimen taken below Ortonville. Again the merging of the microcline into orthoclase is seen. Several slides from fresh specimens of gneiss show orthoclase grains of large size surrounded on two or more sides with microcline. The two feldspars grade into each other so imperceptibly that the boundary between them can not be followed. The former thus constitutes the core, and the relative situation strongly suggests some genetic relationship between the two.

It still more frequently happens that in the midst of large individuals of orthoclase or plagioclase bright, fresh grains and granules of microcline appear. (Pl. XX, *B*.) Less frequently similar small patches of other feldspars, and even other mineral species, are seen. The outlines of these individuals are well defined. All the areas of microcline found within a single individual of orthoclase or oligoclase extinguish together, showing their possible connection in the third dimension. While the relationship in position holds good under the circumstances named, the clusters of microcline, orthoclase, plagioclase, and quartz, so frequent in more altered material, show no such parallelism. Yet it is by no means clear that the smaller included individuals are secondary to the larger ones. They may represent minute quantities of micro-

¹ The greenstone-schist areas of the Menominee and Marquette regions of Michigan, by G. H. Williams: Bull. U. S. Geol. Survey No. 62, 1890, p. 111.

clinic material caught up in the original individualization of the rock constituents, and maintained to the present time in their mineral integrity. Excellent illustrations of this phase of mineral association are shown in specimens 5315, 5320, and many others (see Pl. XX, B).

Several varieties of plagioclasic feldspars are present in varying quantity. At one extreme, in the large number of individuals measured, the extinction angle along the twin lamellæ is between 1 and 4 degrees, pointing to a soda feldspar.

The microcrystalline feldspars, while occasionally appearing in the larger individuals of feldspar, are as a rule distributed among the grains of quartz, also microcrystalline. They are always much more transparent and more strongly polarizing than the primary individuals just described; in optical characters they are almost identical with them.

Some features shown by the microcrystalline feldspars are marked. For instance, the outlines of all the grains are sharply defined by contact with neighboring grains. Occasionally an interlocking of material occurs, yet this habit is not so common as among the quartzes. Very few impurities or intergrowths are seen in these areas, and they are poor in bisilicate individuals. Accessory minerals are also rare, apatite being almost unknown in these portions of the slides.

Biotite.—This mineral is everywhere present and often bears unmistakable evidence of being secondary. As a rule it is associated with hornblende. The latter mineral occupies the major place among the bisilicates in the sections cut from the freshest rocks; more altered rocks show the biotite and hornblende in about equal proportions; and samples taken from those portions nearest the surface and most thoroughly altered show little hornblende, but biotite is plentiful. In these weathered portions the biotite is well individualized, yet even here the areas are either small in size or complex in structure. Where the areas are not complex they are noticeably scattered through the rock, much more than are the individuals of quartz and the several feldspars.

The general characters of biotite so often described obtain here; therefore little need be said on that subject. Several specimens show a marked radial arrangement of the biotite. The individuals appear decidedly acicular in form, and shoot out from a common center in all directions, forming rosettes of long, slender crystals. A well-marked porphyritic gneiss (sp. 5262) from the middle of the valley, shows in one of the quartz individuals a decidedly rosetted arrangement of the biotite (Pl. XX, A).

Inclusions of rutile, or some mineral similar in habit, are rather frequent in the biotite of the most altered gneisses. As a rule this mineral assumes the form or position of a sagenite web, but many needles were also noted, identical in their external characters with those seen in the quartzes and feldspars associated with the biotite.

Another mineral forming an interesting inclusion in the biotite of several localities in the southeastern portion of the valley is quartz. Beautiful lenticular aggregates of clear grains of this mineral are seen in certain exposures (sp. 5186 and 5199, from the Fort Ridgely district; Pl. XX, C) toward the lower end of the valley. Epidote as well as quartz occurs in this situation, and in many cases it is difficult to tell, without a close examination, whether the lenticular aggregates are composed of the one or the other of the two minerals named.

Muscovite.—Nowhere in the whole valley, so far as the rocks were sampled, is muscovite as prominent as biotite and hornblende. Wherever it is present it is associated with biotite or is its representative. So it can not be said that this is an essential rock constituent in the valley. It may be added, in passing, that muscovite is surprisingly rare in the gneisses and granites of the whole State of Minnesota. Within a restricted area southeast of Ortonville, in the old channel of the Minnesota River, or its predecessor, the River Warren, it occurs in nearly equal amount with biotite (sp. 5336 and 5337). In these specimens it bears every evidence of being a secondary mineral derived in large part, if not wholly, from orthoclase and microcline. As a rule it may be said that the muscovite appears as small secondary folia within the large idiomorphic feldspar individuals or around their borders (sp. 5338; Pl. XVIII, A). It is rare that large, independently formed individuals of muscovite are seen. The folia, as they lie within the feldspar matrix, are clustered either in the centers of their hosts or in somewhat irregular bands about halfway from the center to the circumference, the bands taking the shape of the contour of the feldspar individuals. This clustered condition of the muscovite individuals has been noted by G. H. Williams in the granite-porphry of the Horse Race,¹ although there the muscovite clusters occupied the centers of the orthoclase crystals.

The optical characters of this mineral in these rocks are not different from those described by investigators who have worked in other regions. Usually the color is white, and the areas are free from inclusions and are very transparent, so that with ordinary light it is only by the detection of the cleavage striæ that the mineral would be recognized.

Hornblende.—This mineral occurs in a few localities in large isolated idiomorphic individuals. While these individuals suggest a porphyritic rock, the evidence that these rocks are porphyries is still lacking. The individuals are sharply defined. Their internal organization shows a homogeneity of structure, indicating a continuity of building noted in the old crystallines only, in which that building has been practically a continuous process. From the material at hand it is not shown that the formation of this mineral took place in two generations—a process necessary in the development of a porphyry.² The

¹ Bull. U. S. Geol. Survey No. 62, 1890, p. 117.

² Synopsis of Rosenbusch's new scheme for the classification of massive rocks, by W. S. Bayley: Am. Naturalist, Vol. XXII, 1888, p. 209.

usual characters of hornblende, as described by Rosenbusch, Fouqué and Lévy, and Rutley, are seen.¹ The mineral appears in clusters of small individuals (sp. 5255, 5310). The color is, without exception, green. The dichroism is strong, giving a brownish dark-green when parallel to *c* and a bright green in the direction of *a*. In the arrangement of these hornblende individuals there is little regularity. When the gneissic character of the rocks is brought out through the parallel position of the porphyritic feldspars, hornblende takes a subordinate place, both in quantity and in function, and displays a less tendency to parallelism than do the feldspars.

Another interesting phase of the hornblende of these gneissic rocks is the fibrous variety. This gives the uralitic character first described by G. Rose many years ago.² The chemical composition of this variety of hornblende has not been determined. A typical locality, if the writer understands the type, is found in the quarry recently opened at Granite Falls, just west of the tracks of the Great Northern Railway. The rock is rather dark colored, possesses a distinct gneissic structure, and is rather coarsely granular. The bisilicate constituent was once a pyroxene, and even now some traces of that mineral are seen. For the most part it has changed to the fibrous modification of hornblende. The color of the alteration product is light green in some fibers, while others show an almost entire lack of color. The fibers lie in approximately parallel positions, although often a tendency to a radial arrangement is seen, especially where some portion of an old pyroxene (augite) area serves as a nucleus of crystallization.

In other localities—for instance, at La Framboise's—a similar occurrence of the fibrous hornblende is to be seen. The relations of the hornblende to the small areas of augite which are seen at this locality must remove all doubts as to its origin from this mineral, even though doubts remain concerning the secondary nature of the few isolated biotite folia which most thin sections of these interesting augite-biotite-granite-gneisses disclose.

The fibrous hornblende is not so frequent in the gneissic rocks of the valley as it is in the gabbroids described in Chapter V. It may be said, however, that in the gneisses represented by the specimens collected there appears to be a rock which stands on the borderland between the great gabbro family, so widely distributed in northwestern Minnesota, and the great mass of Archean gneiss typified in the exposures of central Wisconsin.

The relation of this mineral to the feldspars indicates that the hornblende took a secondary place in the process of crystallization. Along the lines of contact the feldspar individuals are bounded by surfaces which in many instances closely approximate to crystal faces, while the

¹ *Mikroskopische Physiographie d. pet. wichtig. Mineralien*, by H. Rosenbusch, 3d ed., 1892, p. 556 et seq. *Ibid.*, Iddings's translation of 2d ed., 1888, p. 244. *Mineralogie Micrographique*, by Fouqué and Michel-Lévy, 1879, p. 365 et seq. *Rock-forming Minerals*, by Frank Rutley, 1888, p. 184 et seq.

² *Reisen nach dem Ural*, 1837 and 1842. Also *Neues Jahrbuch für Min.*, 1833, p. 424; 1834, p. 652.

hornblende lying in contact with them assumes the shape thus determined. Occasionally smaller individuals of hornblende are well formed and show very complete sections of crystals, but this is a rare phenomenon. In color there is much variation, the green usually prevailing. In the gneisses, as a rule, the hornblende is unusually free from inclusions, although in the gabbro series it abounds in them, as will be stated in Chapter V. Where mineral impurities occur, epidote, rutile, and biotite occupy the leading place.

Very frequently a close relationship is seen between the biotite and the hornblende. As has already been mentioned, the last-named mineral shows every indication of secondary origin. It lies in clustered aggregates, and seldom is an area composed of a single individual. The hornblende individuals bear no evidence, in their association and structure, of being primary. They can not be found in these rocks associated with some pyrogenic constituent and the steps of change from the latter be followed step by step, as can be done in the gabbroid granites of Rhineland, Wisconsin, and in the hornblende-biotite-granites of central Minnesota; but in studying the series as a whole, from one end of the valley to the other, every stage in the alteration process can be seen, from the fresh augite individuals to those firmly knitted, brown hornblende areas which represent the mature stage of this mineral. From the general composition of the hornblende clusters, from the association of other minerals, and from the presence among them of secondary quartz and feldspar granules the secondary origin of the hornblende is most confidently assumed.

Again, among these gneissic rocks phases, with many intermediate steps, appear, in the one of which the genesis of the hornblende can not be read, in the other of which it can be read with high assurance of correctness. The relations between these two types are so close, and their mineral conditions are so nearly identical, that one can not well avoid carrying the conclusions reached in the study of the latter phase over into interpretations of the former, and asserting the same conclusions in respect to it. Hence the writer has reached the conclusion that there is no such thing in the Minnesota River Valley as original or primary hornblende. For other portions of the Northwest, where the so-called Archean rocks appear, investigators have announced similar conclusions. For instance, Irving stated, while studying the Wisconsin Valley:

"Mr. Van Hise's study shows now that augite, so far from being a stranger to such rocks as gneiss and granite, is nearly as common a constituent, so far at least as this region is concerned, as hornblende or mica, and that all of the hornblende of the rocks of this region is but altered augite."¹

Wadsworth, who examined the gabbros of the Northwest, believed "all the hornblende seen . . . to be secondary . . . In color

¹ Geology of Wisconsin, Vol. IV, Part VII, 1882, p. 714.

it varies from a light or yellowish green to a dark brown or yellowish brown . . . the darker stages being simply the more perfected condition of the greener or uralitic stage."¹ Lawson, for the Rainy Lake region, recently studied by him, said that "it seems not improbable that all the hornblende of the hornblende-syenite and granite [granite gneiss] of this region is of secondary origin."² Further, Geo. H. Williams, Judd, Schuster, and many others have noted the alteration of augite into hornblende in other parts of the world. Laboratory experiments³ have been made, extending through a long series of years, in endeavors to show that hornblende represents the stable molecular arrangement of this already much-studied metasilicate compound.

The hornblende and biotite are, in all the granitoid gneisses sampled, extremely sparse. The only exception is seen in the rocks of the bottoms just above old Fort Ridgely, where a liberal sprinkling of hornblende and biotite can be seen over two or three areas. Basic inclusions were found in the rocks in their ordinary phases, while none were found in the acidic gneisses. In sec. 2, T. 11 N., R. 33 W., there are a number of inclusions of various sizes, well defined, schistose in structure, rather fine in texture, and a hornblende-biotite-schist or gneiss in mineral composition.

Augite.—In their present altered condition the normal gneisses of the Minnesota River Valley carry augite in only two or three localities, so far as the gathered hand specimens show.

Of these localities, the first to be mentioned is that around La Framboise's and Hindarmann's farms, below old Fort Ridgely, in secs. 15, 16, 22, and 23, T. 109 N., R. 32 W. (sp. 5191, 5192, 5721, 5722). The second locality is at Granite Falls, in sec. 31, T. 116 N., R. 40 W. (sp. 5768 and 5769).

Only a small quantity of augite is present in the freshest of these exposures, and even this shows partial alteration, save in one or two slides from the La Framboise locality. Two or three hand specimens from this place present the alteration of augite into biotite without disclosing the intermediate stage of hornblende-building. At Granite Falls the alteration into fibrous hornblende of some mineral which is presumed to have been augite has already been discussed. It may be remarked here that in all the slides cut from gneissic rocks where augite is present the proportion of basic minerals is extremely small.

Pyrite is to be seen nearly everywhere, but, as a rule, it is sparse. Under the railway tracks near Odessa, sec. 31, T. 121 N., R. 44 W., there is a comparative abundance of iron sulphide, probably marcasite. It occurs in segregations of small size. Some blocks have been blasted out and their surfaces are stained with iron rust from the alteration of

¹ Preliminary description of the peridotites, gabbros, diabases, and andesytes of Minnesota, by M. E. Wadsworth: Geol. Nat. Hist. Survey Minnesota, Bull. No. 2, 1887, p. 66.

² Report on the geology of the Rainy Lake region, by Andrew C. Lawson: Ann. Rept. Geol. Nat. Hist. Survey Canada, 1887-88, p. 125F.

³ Geo. H. Williams has enumerated the chief of these. On the paramorphosis of pyroxene to hornblende in rocks, by Geo. H. Williams: Am. Jour. Sci., 3d series, Vol. XXVIII, 1884, p. 250.

these segregations. This alteration is so rapid that only on comparatively fresh surfaces can any of the iron sulphide be seen. Numerous cavities on the older surfaces, and the deep stains of iron rust, point to the former existence of the compound. In other localities clusters of pyrite crystals are to be seen, but nowhere in sufficient quantity to deserve particular notice, and probably in no place save the one mentioned in such quantity as to have a deleterious effect on the stone for economic uses.

Magnetite appears in many slides, but nowhere in quantity visible to the unaided eye. In its occurrence it bears evidence of secondary origin. It usually lies clustered about the spots where bright-green hornblende and minute, clear grains of secondary quartz are segregated. In several sections beautifully segregated masses occur, notably in the larger dike west of Granite Falls (sp. 5286).

Hematite is present in about the same quantity as magnetite. It appears in the surficial, most-altered portions of the rock. Where the rock crumbles the heaviest accumulations of this mineral appear. In such situations the cleavage planes of the feldspars are stained, as well as the opened contact zones between these and the other constituents. More rarely the hematite stains hornblende and chlorite clusters so that the appearance is that of a fibrous or radiated hematite.

Limonite is distributed as is hematite. Indeed, these minerals are usually distinguished by their colors. So far as their associations go, hematite and limonite merge into each other in many cases in such a way as to suggest that the only difference between them lies in the hydrated condition of the latter through the influence of percolating waters.

Ferrite.—Occasionally around the areas of hematite one sees a whitish or light-brown, finely granular, closely packed iron substance, sometimes arranged in well-defined areas, as if the material were a pseudomorph after some preexisting mineral, now totally removed. Not infrequently this preexisting mineral would seem to be magnetite. From the difficulty found in separating it from a stained kaolinic decomposition product, almost everywhere abundant in the much-altered gneisses, no satisfactory determination of the mineral can be made, and so it is given the general name *ferrite*.

Rutile is present in minute, needle-shaped crystals which penetrate all the leading constituents of the granitoid gneisses. It was only in the biotite that any regularity whatever was noticed in the arrangement of these crystals. Here occasionally a strongly marked network of needlelike crystals can be seen in such sections as are cut at a low angle to the cleavage. In the quartz rutile is a most frequent impurity, especially around Fort Ridgely and Ortonville, as has been elsewhere stated.

Apatite, in the usual needles, is a frequent accessory. Often a broken condition indicates great pressure exerted at some early or middle transition stage in the alteration of the rocks.

Kaolin.—This is an extremely interesting alteration product. It is very general in its distribution. The freshest specimens disclose only traces, but the gneisses of Birch Cooley, Redwood Falls, and thence locally as far as Granite Falls, are so completely broken down as to be soft and unctious to the touch. Here kaolin is one of the two or three abundant secondary minerals present. Between those two extremes—the fresh, firm rocks on the one hand and the completely decomposed varieties on the other—lie numberless phases of alteration. Ordinarily the kaolin occurs in minute elongated leaflets, which resemble very closely in all outward characters minute folia of muscovite. They are very clear, white, and strongly polarizing. Indeed, in many cases it is more than probable that muscovite and kaolin are intermingled.

Epidote is a mineral of no small interest in the study of these rocks. In all the sections examined not one crystal of this mineral was seen. There are two modes of occurrence:—the granular, where the mineral lies in isolated or segregated individuals of varying size, from the extremely minute to those which compare in area with those of quartz and feldspar; and the radial, where from a central point radiating grains shoot out into the substance of the host, giving a bright, rosette-like field in polarized light.

Epidote is singularly free from inclusions. Rarely fluid inclusions can be seen. Here and there an intergrowth with other minerals was noted. Nowhere does epidote present the features of a primary constituent of the rocks carrying it. It is most abundant in the extremely weathered rocks. Thus beneath rock surfaces long exposed to the weather and in proximity to thin bands or veins in the gneissic masses epidote should be expected; but in the deeper alterations, like those which have resulted in the kaolin of Birch Cooley, only occasional traces of it are to be found. It is sometimes present in the midst of feldspar individuals, much altered from their original chemical and physical conditions.

Chlorite also is an accessory. Although rather frequently met with, there are only two or three localities where it is sufficiently abundant to receive special consideration. On Tracy's farm, sec. 10, T. 112 N., R. 34 W., is the most conspicuous locality found. Here one knob of gneiss with coarse and indistinct foliation, somewhat jointed, with large feldspar individuals, and abounding in dark-colored inclusions, exhibits the most beautiful individuals of chlorite thus far seen by the writer in Minnesota. Radial areas and chains of hexagonal plates are beautifully developed, and show the characteristic optical characters of the mineral. (Pl. XVII, A.) It seems to spring from the decomposition of both basic and feldspathic constituents, although it is doubtless true that the basic minerals play the leading rôle.¹ It is associated with quartz, and lies usually in clusters and bands of secondary formation.

¹ Compare Rosenbusch, *Physiographie d. pet. wichtigen Mineralien*, 3d ed., 1892, p. 598; also *ibid.*, Iddings's translation of 2d edition, 1888, p. 188.

The other localities in the valley where chlorite appears are the neighborhood of old Fort Ridgely, Redwood Falls, Beaver Falls, and at several localities around Granite Falls and Minnesota Falls. At all these places both the hexagonal plate and the radial cluster are absent. Occasionally a large area having the ordinary characters of hornblende has the optical reactions of chlorite; again, small isolated individuals are discovered.

HORNBLLENDE-BIOTITE-GRANITE-GNEISSES.

In ascending the Minnesota Valley the first gneissic rocks one meets are granite-gneisses. There are four areas where the rocks are more distinctly granitoid than elsewhere in the valley: Around old Fort Ridgely (Pl. IV), below Ortonville (Pl. XIII), on the "rock barrens" in T. 114 N., Rs. 37 and 38 W. (Pl. VIII), and around Vicksburg, 5 or 6 miles southeast of the "barrens" and practically midway in the valley between New Ulm and Ortonville (Pl. I). In all the areas named the granite-gneisses carry inclusions, sometimes of large size, of schistose rocks. They are, save at Ortonville, in contact with the ubiquitous gabbroid schists. Everywhere within them are seen numerous quartzose and granitic veins. The granite-gneisses are everywhere hornblendic, and usually carry so much of that mineral associated with the biotite that they are hornblende-biotite-gneisses.

ORTONVILLE AREA.

Beginning a little below the city of Ortonville, and extending for 10 or 12 miles down the Minnesota River Valley, lies a series of knobs of granite-gneiss. There are places where for a mile and more no bed rocks can be seen, the débris of the ancient River Warren and of the Minnesota having covered them. The largest exposures are several hundred paces in extent, and occasionally reach heights of 50 to 75 feet above the bed of the river. The map, Pl. XIII, locates the ledges with sufficient detail save when some special character is to be noted. The peculiar billowy aspect produced by the glaciated surfaces of these gneissic rocks immediately below Ortonville has already been mentioned; so, too, has the direction of the glaciated striae, together with the morainic movements which produced them. In structural characters there is some variation. On the ledges nearest Odessa there is seen a massive structure which only occasionally discloses a genuine lamination. Yet as one looks at the polished surfaces of the rock a distinct parallelism in the position of the idiomorphic feldspars is seen.

Passing eastward to the series of exposures between the village of Odessa on the north and the Yellowbank Creek on the south side, one finds a distinct gneissic structure prevailing. The strike of the laminae is, on the most typical exposure, nearly N.-S., with a dip of from 40° to 45° E. (sp. 5320, 1,400 paces N., 600 paces W., sec. 30, T. 121 N., R. 45 W.). The strike and dip cited for that exposure do not, however, everywhere

prevail. A variation to a strike NE.-SW. can be seen within two-thirds of a mile, and doubtless exists much nearer. Still farther to the east and south are exposures showing conspicuously the parallelism of the idiomorphic feldspars mentioned as so plainly seen near Ortonville. Under the railway track, near milepost 168 from Minneapolis, on the Chicago, Milwaukee and St. Paul Railway, lies a considerable mass of granite-gneiss (sp. 5312, 5313). It contains inclusions of a schist, and is interlaminated with a more distinctly gneissic type of rock. It has been quarried for trestlework, and a good view of the fresh surface can be had. A mile or so to the west, and just south of the railway, lies another low exposure of very similar habit. The mineral constituents are here very fresh. One mile south of this spot, in a bend in the river, are several exposures of a similar granitoid type, carrying considerable biotite. The rock here has a reddish color and is rich in feldspars. The direction of these feldspars is NE.-SW., with scarcely a trace of mineral segregation into gneissic laminae. Yet only a few hundred paces to the southwest a knob of sharply gneissic rock stands up in the bottoms. The individuals of feldspars—there are several species in these rock masses—are quite fresh, and their outlines are well-defined against the matrix. All species alike show the usual inclusions, even with the unaided eye.

In the old river valley, a mile and more to the south of the Yellowbank Creek, is a series of exposures. The most southerly knobs are almost entirely devoid of foliation; for instance, those on the Parmenter farm, in sec. 22, T. 120 N., R. 45 W. (sp. 5337), and another a half mile west (sp. 5336). Some show a parallelism of the feldspars (sp. 5338), while others exhibit interlaminated schists and a varying gneissic condition of the acidic rock.

The easternmost exposures represented on the map (Pl. XIII) consist of a pair of knobs of considerably finer grain than the gneisses to the west. A sharply defined parallelism marks a NE.-SW. direction, with a dip to the SE. of 40° to 45° . Smoothly glaciated surfaces of some of the highest knobs show striae pointing S. 30° E. to S. 40° E., which is the general trend of the valley in this upper portion.

The jointing of these rocks was everywhere noted. Broadly speaking, there are two systems of joints, one having a NE.-SW. direction, and the other a NW.-SE. direction; but there are minor joints. Around Ortonville joints are comparatively rare. The view of Baxter & Son's quarry, shown in Pl. XIV (p. 40), gives an accurate representation of the massive character of the granite-gneiss at this place.

In color the granite-gneisses of the upper valley are a light red. Pl. XVI, A, shows the color and texture in natural size. Exposure modifies its tone somewhat, but where river silt and glacial débris have kept the surface covered it is strikingly fresh. Examination shows that the color is due to films and flecks of ferric oxide infiltrated along the contact surfaces and cleavage planes of the mineral grains. The origin

of the ferric oxide is not so clear. The first source to suggest itself is the covering of glacial drift, which everywhere contains a perceptible percentage of this compound. But in the deeper parts of the extensive quarry at Ortonville the rocks are as brightly colored as near the surface.

The microscopic characters of these rocks have already been briefly described in this chapter.

Ordinarily a medium texture prevails. This becomes somewhat coarser in certain lenticular areas which are doubtless due to a segregation process. At other places rather finely crystalline, almost microcrystalline, patches are seen.

Feldspar is the leading mineral. The larger individuals are mostly idiomorphic, frequently affording bright cleavage surfaces and minor fractures. Their transparency is so great that they remind one of shattered quartz. Some mineral inclusions are present, the most frequent being quartz, in spherical and elliptical grains, and other species of feldspar. For instance, within the oligoclase areas are small, fresh microcline individuals. Somewhat rarely the polysynthetic twinning of the triclinic individuals is clearly seen. The alteration products of the feldspars, save the quartz just mentioned, can not be seen with the unaided eye. Where the quartz is of the first generation it has the skimmed-milk blue color so common in the granitoid rocks of the entire valley. A peculiar opalescence results from this, which is noticeable on fresh fractures. In the granite-gneiss of ordinary texture quartz of the peculiar opalescent phase is abundant. In the finest-grained specimens the quartz is subordinate, the feldspars, with a few areas of biotite, making up the mass of the rock. Where the rock becomes coarsely granular or pegmatitic, quartz assumes an increased importance. In these places it is more transparent than is usual. It extends in irregular bands and masses between the feldspars, and thus plays the rôle of a matrix.

The bisilicate constituent, biotite, is not a conspicuous one. In many instances hand specimens fail to disclose its presence. Again it appears in such quantities as to make the darker-colored bands giving the foliated condition seen on many exposures.

Hornblende is not abundant in the Ortonville exposures. It is seldom seen in the surface specimens, and plays a very unimportant part in those taken from the depth of the quarry. Enough is present, however, to give a hornblendic character to the rock. It is usually scattered about in isolated grains. An apparent exception is seen in the clustered condition of the granules in the rare bisilicate nodules. Here the hornblende and biotite are mingled in irregular and thickly strewn folia, all assuming one general direction.

The leading accessory mineral in the granite-gneisses of the upper portion of the valley is an iron sulphide. Yet even this mineral occurs only rarely around Ortonville or south of the Yellowbank. At the

railway cut in sec. 31, T. 121 N., R. 44 W., it is more plentiful. When blocks have lain exposed to the air for some time heavy stains of iron rust appear. From the readiness with which the sulphide decomposes it is believed to be marcasite rather than pyrite.

A single chemical analysis of the Ortonville granite-gneiss was made by Mr. A. D. Meeds, of the University of Minnesota. The results confirm those of the microscopic examination as to the nearly equal proportions of potash, soda, and lime feldspars, the sparse distribution of the bisilicate constituents, and the comparative richness of the rock in quartz.

Analysis of Ortonville granite-gneiss.

Constituent.	Per cent.
SiO ₂	74.40
Al ₂ O ₃	14.06
Fe ₂ O ₃	3.84
FeO.....	1.23
CaO.....	1.73
MgO.....	0.29
K ₂ O.....	1.83
Na ₂ O.....	2.17
H ₂ O.....	0.26
Total	99.81

VICKSBURG AREA.

Around Vicksburg for several miles there lie huge masses of granite-gneiss. In places a very massive appearance is seen, and again a distinctly foliated condition prevails, where great contortion characterizes the surface. There is almost no interruption in the occurrence of exposures as one approaches the Vicksburg ferry from Redwood Falls. Some of the exposures stand high above the river bottoms, reaching well toward the height of the bluffs of glacial débris, and others are low in altitude and insignificant in area. Strike and dip here, as everywhere else, vary considerably. In sec. 13, T. 113 N., R. 36 W., a reddish, clearly foliated gneiss (sp. 5384) of medium texture strikes N. 80° E. and dips 30° S. The outcrop stands on a bench in the bluff, and reaches an altitude of 45 to 50 feet above the bottoms through which the present river has cut its channel. The chief mineral constituents of this rock are quartz and microcline. Other feldspars are extremely sparse. Quartz is present in at least two generations. The few small areas of hornblende are partially chloritic, and in nearly every instance carry minute grains and needles of what was regarded as titanite. The rock shows evidence of alteration of its feldspars and bisilicate constituents. Some of the more-altered feldspars of the ancient generations contain small folia of secondary muscovite.

FORT RIDGELY AREA.

Opposite New Ulm, in sec. 27, T. 110 N., R. 30 W., is a granite-gneiss which is weathered to an extent much beyond that of the ordinary gneisses of the valley. This is due largely, no doubt, to its protected position at a lower level than the beds of basal conglomerate lying in its immediate neighborhood. An apparent bedding prevails, dipping 15° to 20° toward N. 50° E. The jointing is extremely marked and the rock, as a whole, is greatly shattered. The habit of the rock is porphyritic, orthoclase crystals being often an inch or two in length. They crumble easily. The red color characteristic of this group of exposures lies in the feldspars. Considerable white quartz is seen in the form of veins. These veins are, as a rule, lenticular in shape, yet sometimes they are in narrow, tortuous bands. The basic constituents consist largely of hornblende, with occasional grains of epidote. The quantity of biotite present is small, and only a few small folia of muscovite were seen.

In the neighborhood of old Fort Ridgely the granitoid gneisses are much fresher, firmer, and more massive than in the exposures near New Ulm. At the old ferry and ford, where some years ago quarrying was done for the barracks at the fort, and a little farther up the river, on the line between secs. 1 and 2, T. 111 N., R. 33 W., lie extensive exposures. The rock shows a lamination in the somewhat rare bands of more basic material and in the arrangement of the large porphyritic feldspar individuals (sp. 5415). While the rock shows in places considerable contortion, the general direction of the laminae is N.-S. The dip is westerly, averaging 50° . The red color which here largely prevails is due to a staining by ferric oxide which has penetrated the cleavage crevices of the feldspars.

Both original and secondary feldspars are present. In many original feldspar individuals the inclusions are so large that they can readily be seen with the unaided eye. They are chiefly granules of quartz, hornblende, and biotite, although some interesting intergrowths of the feldspars were seen (sp. 5187, 5188). Frequently the sides and ends of the idiomorphic feldspars are corroded to such an extent as to show marked irregularities in outline. There is little orthoclase, the primary and in large part idiomorphic individuals which the rock contains being mostly microcline and one or more plagioclastic varieties. In size they are frequently an inch or more in length. The characteristic crosshatching of the microcline is sharply drawn, few individuals being so decomposed as to have the marking obliterated. Frequently crystals show beautifully both the Carlsbad and the polysynthetic twinning. In places there is a narrow reaction rim around these microclines as they come in contact with the albites and quartzes. As the result of a number of measurements, the triclinic feldspar is found to vary between 1° and 12° in extinction angle, and is therefore regarded as oligoclase albite. It shows more alteration than the microcline.

The genetic relations of the two varieties were not studied at this particular locality. The twinning striae are very fine and are often considerably altered along their boundary edges. Instances are noted where half of an individual is strongly twinned and the other half is entirely free of twinning striations. Other cases occur where on either side of a feldspar area the strong crosshatching of microcline can be seen, while the middle part of the grain bears every evidence of orthoclase.

The secondary feldspars consist of small, transparent, brightly polarizing areas, and are of very frequent occurrence in all varieties of the mineral. These secondary individuals are usually free from inclusions. They are arranged in strings and bands in the midst of the interstitial matter which surrounds the minerals of primary consolidation.

Quartz occurs in two generations. Biotite and hornblende are present in nearly equal proportions, the former in much better-defined areas than the latter. In many of the hornblende areas there lie many granular inclusions of an opaque material which bears every evidence of secondary origin. Its nature could not be clearly determined; it may be pyrite. Cubes of pyrite are occasionally seen. Sphene in small quantities was noted. In the areas once occupied by the primary basic constituents are clustered hornblende granules mingled with secondary quartz, biotite, and some opaque material, probably either magnetite or pyrite. The position and associations of these granules suggest their derivation through the alteration processes which have obliterated the original minerals and made possible the nests of clustered secondary minerals.

Veins or lenses of quartz were noticeable in one or two exposures, particularly at 1,500 paces N., 750 paces E., sec. 2, T. 111 N., R. 33 W. They vary in width from a fraction of an inch to 4 and more inches. Horizontally they rarely extend more than 6 or 8 feet. Their general direction is N. 65° W. The quartz of these veins is somewhat opalescent, although less so than in the veins crossing the augite-gneiss at La Framboise's and Hindarmann's farms 5 miles down the river. This character is due, doubtless, to the minute crystals regarded as rutile which abound in this mineral. Jointing is very conspicuous in the neighborhood of Fort Ridgely. Upon the mass just located conspicuous joints run N. 80° W. across the water-eroded surfaces. They dip southward at an inclination of 65°. Another system of joints, at right angles to the first, dips westward at the same angle, viz, 65°. Joints with similar directions appear at the old Government quarry in the same section and only 300 paces away to the northeast.

Along what seems to be a boundary between the dark-colored and reddish phases of these gneissic exposures lie several interlaminated masses of a hornblende-biotite-schist. These masses vary greatly in size, some of them being no larger than hen's eggs, while the largest extended so far downward and under the turf that its boundaries could

not be determined. The texture of these inclusions is medium; their structure is distinctly schistose. As they weather at the surface they seem to bleach, through the alteration of the dark-colored constituents. These inclusions occur in many other places over the surfaces of these exposures than at the contact zone named; yet along this zone they seem to be segregated. The contact between the inclusions and the granite-gneiss containing them is sharply drawn. A porphyritic condition of the rocks is elsewhere shown through the development of the feldspars. So far as the basic constituents appear to the naked eye, they are finely granular and lie in the angles and along the contact zones of the feldspars. The quartz areas, wherever they can be seen, assume a like position, but this position is noted in the clusters of grains as they lie in the rock rather than in the direction of the crystallographic axes of the individuals.

AUGITE-BIOTITE-GRANITE-GNEISSES.

LA FRAMBOISE AREA.

In several sections around La Framboise's farm, 15 miles in an air line northwestward from New Ulm, occur many large masses of a fresh, firm, granitoid gneiss. Near the stage road, and just under the projecting morainic northeast wall of the valley, stands a very siliceous red rock (sp. 5193). The whole exposure is shattered into rhomboidal blocks by joints running N. 75° E. and N. 10° E., the former set dipping 60° SE. and the latter 70° SW. The lamination of the rock, which is very obscure, strikes N. 20° to 30° W. and dips at an angle of 20° S. Toward the river the rocks assume a grayer color and are much less shattered. Their surfaces, which are waterworn and not glaciated, are grooved and undulating, and disappear at a gentle angle beneath the turf. Yet several abrupt faces 30 to 50 feet high show considerable erosion. The texture is medium, but it varies in places to a finely granular, granitic type. Microcline individuals several inches across are met with. Inclusions of the gabbroid rocks also appear, with sharp contacts wherever contacts can be seen, but their area could not be made out, owing to the covered condition of the rocks. A banded structure appears at times, but the usual evidence of gneissic character is the parallel arrangement of the constituent minerals, particularly the feldspars.

At Hindarmann's farm, a half mile west of La Framboise's, a distinct lamination is developed through the segregation of biotite. More rarely, too, a lamination is produced by the development of lenses of quartz in the shape of thickenings of siliceous veins. In color the more laminated portions of the exposures are the darker, the color appearing to lie as much in the feldspar as in the quantity of biotite and its representative. Where the color is red, it is due to infiltrations in the interstices of the feldspars and in the crevices between the feld-

spars and the quartzes. The gray color varies with the condition of the feldspars.

A microscopical examination shows these granitic gneisses to be pyroxenic, and that the pyroxene is to a considerable extent hypersthene. This constituent occupies but a small place in the mineral composition of the rock. Only now and then will a section show its presence. The grains are small and irregular. On the cleavages and other fractures of the grains alteration has changed the pyroxenic material to a fibrous biotite. Rarely the product of the alteration is a hornblende, and in two or three places chlorite was seen. This pyroxenic constituent is of two kinds, apparently about equal in quantity, one of which shows more or less dichroism (depending on the thickness of the section), a parallel extinction, and the sharp prismatic cleavage of hypersthene; the other appears in more or less rounded grains, irregular cleavage, little or no pleochroism, and with the high extinction angle of augite. The alteration products of the two minerals seem to be identical, their color and degree of transparency being about equal. Inclusions, except as they bear some relation to the alteration processes, are very rare and insignificant. Surrounding most of the pyroxene grains of both kinds are the alteration products, biotite and small, brightly polarizing quartz grains, with occasionally some minute individuals of hornblende.

Several varieties of feldspar are found in the rock. The plagioclases, when measured in the zone, all exhibit the low extinction angle of the albite end of the series, from 2° to 10° being the usual measurements. The plagioclase seems to show more alteration than the orthoclase and microcline. Cloudiness generally obscures the twinning planes, and areas of clear quartz of minute size frequently stud their surfaces, derived, apparently, through the decomposition of the feldspar areas in which they lie embedded. Microcline is present in many large, well-defined individuals. More rarely areas show the optical characters of orthoclase. These two varieties are free from alteration phenomena, yet they exhibit undulatory extinction to an unusual extent, and in places (sp. 5179) induced cleavage phenomena are disclosed.

Quartz plays an important rôle. The larger and more conspicuous individuals exhibit large numbers of liquid inclusions and many long, needlelike crystals of rutile. This last-named mineral is found in large quantities in the feldspars also. In many areas in proximity with the feldspars a microcrystalline condition of the quartz is rather prominent, showing all the indications of a secondary origin. Isolated minute grains occur frequently within the feldspars, particularly the plagioclases. Vermicular quartz is conspicuous in many slides (sp. 5179, 5193), and seems to grade into the granular quartz already noted. One character which is noticeable in all the slides is the sharp outline of all the quartz areas against the discolored edges of the feldspars. Apatite in needlelike crystals is sparsely present.

As might be expected from the small proportion of the basic constituents to the whole mass, the rock is acidic. Specimen 5179 was analyzed by A. O. Dinsmore and W. P. Milliken in the laboratory of the University of Minnesota. It was selected as a representative sample of the granitoid type. It contains quartz and a mineral that acts optically like orthoclase feldspar, both in large proportions. A plagioclase of low extinction angle occurs in a few grains so altered that only in places could the twinning striæ be clearly made out. The alteration products are a kaolinic substance and vermicular quartz. The basic constituents appear in exceedingly small quantity. They are biotite and hornblende.

Mr. Otto K. Folin analyzed specimen 5723, which represents the more schistose portion of the rock at La Framboise's. Taken near the surface, it shows some discoloration, due to weathering, and doubtless a larger proportion of biotite is present. In field characters this specimen can not be separated from the granitoid phases with which it is in several places associated.

Analyses of granitoid gneisses.

Specimen 5179.		Specimen 5723.	
Constituent.	Per cent.	Constituent.	Per cent.
SiO ₂	72.80	SiO ₂	69.012
Al ₂ O ₃	15.40	Al ₂ O ₃	13.730
Fe ₂ O ₃	3.10	Fe ₂ O ₃	0.540
MgO.....	0.65	FeO.....	2.080
CaO.....	3.75	CaO.....	3.701
Na ₂ O.....	3.40	MgO.....	1.080
K ₂ O.....		Na ₂ O.....	4.196
H ₂ O.....	2.00	K ₂ O.....	2.330
		H ₂ O.....	0.130
Total.....	100.60	Total.....	96.799

The schist (sp. 5721) at Hindarman's, less than a mile away, shows, as an average of two determinations, 70.56 per cent of silica. Mineralogically the rock is practically identical with specimen 5723. Specimen 5721 is the more altered. Both are much shattered.

GRANITE FALLS AREA.

Near Granite Falls are localities where rock similar to that at La Framboise's appears. Along the Great Northern Railway, recently built, some quarrying had been done. Extensive work was abandoned when it was found that the rock was so shattered that dimension stone could not be quarried. This is a typical gneiss so far as pertains to structure, although considerable variation can be seen. Inclusions of schist, some of them many feet in extent, are present.

The gneiss is, in general, a rock of medium color. It is strongly foliated by the alteration of quartz-feldspar bands with those consisting

largely of the bisilicate minerals. The quartz and feldspar present the usual characters of these minerals. The latter is represented by orthoclase, microcline, and a plagioclase of albitic extinction. The bisilicate constituents are muscovite, biotite, hornblende, and one or two pyroxenes. The muscovite is present in small folia scattered through a few altered feldspars, and none was seen that did not have that position. The biotite exhibited some folia of large size as compared with the coarseness of grain of the rock. In places a finely granular condition is conspicuous in thin sections. These areas are in such relation to the hornblende and pyroxene that their derivation from these minerals seems clear. The hornblende, while not abundant, is present in numerous places and always in association with the pyroxene. Nowhere, save in the schistose inclusions, was it seen in good-sized independent individuals, but rather as a fibrous uralitic variety, with indistinct optical reactions.

The pyroxene reacts like hypersthene; it shows the dichroism and usually the parallel extinction of this mineral. It does not occur in large individuals, as is the case in the gabbroid rocks of the valley, but the areas are segregations of numerous granules of varying size. Their edges are frequently fringed with the beginning of decomposition, as shown in the uralitic alteration product. The central portions of the segregations, as well as the individual grains, are rather fresh. Accessory minerals are few and of the same species as are met in nearly every gneissic exposure of the valley.

In the same areas in which the above-described augitic granite-gneiss occurs there is also present the normal hornblende-biotite-granite-gneiss. The color, texture, etc., as well as the petrological characters, are different, but there is no place where the field relationships can be seen, and thus a basis be formed for discussing their genetic relations.

AREA IN T. 114 N., R. 37 W.

A rock of special interest occurs in the "rock barrens" in secs. 7 and 8, T. 114 N., R. 37 W. It is a mass of rock quite different in outward aspects and internal structure and constitution from any of the gneisses which lie around it. It varies from them in color and texture, as well as in general habit, to a very marked degree. The color of the rock is reddish, except where augite or biotite predominates, when it becomes greenish or black, or where the feldspar becomes microcline, when a dirty white prevails. The texture is in places very coarse and pegmatitic, and again it is fine and sharply crystalline. Where the texture is coarsest some work has been done in a search for gold, but, so far as could be learned, entirely without success. In this work an excavation of several feet had been made (Ellingson's mine), in which a series of specimens was secured. Here were noted cleavage planes on some of the feldspars which were several inches across. Augite crystals were also broken out which, while in an imperfect condition, were more than an inch in diameter and of still greater length.

Beneath the road, just north of the south line of sec. 7, in the township cited, some blasting has been done. Here the rock has a medium texture, a bright, fresh color, and the feldspars are greatly in predominance. In general features this rock has every appearance of a gabbro. The color and habit of the feldspars, the presence of augite, the tendency in this mineral to alter into hornblende and biotite, the segregated condition of the mineral constituents, all tend to give a decidedly gabbroid and nongneissic aspect to the rock.

The boundaries of this group of exposures are hard to follow, as the surface is to a great extent covered with grass. Everywhere that rocks were sampled at short distances from the above exposures they proved to be the ordinary red hornblende-biotite-gneiss or simply biotite-gneiss. It is clear, therefore, that this series of specimens (5372-5375, inclusive, and 5748-5754, inclusive) does not represent a rock variety of great extent or wide distribution. The only other place in the valley where similar features were seen was at Morton, where certain inclusions in the ordinary gneiss gave an appearance similar to this. Yet at Morton a gneissic arrangement of the mineral constituents is very pronounced, while here, on the rock barrens at the Ellingson location, the gneissic character is due partly to the direction of the feldspars in the ordinary texture of the rock.

There is nothing of note in the weathering of this rock variety. All its phenomena are identical, so far as observed, with those of the ordinary gneisses of southwestern Minnesota. Where the texture is coarse the corrosion or weathering has been greatly accelerated.

There are observed various gneissic phases from the granitoid to the well-defined gneissic alteration of bisilicate and feldspathic bands of mineral constituents. A strike of the banding N. 70° E. is seen, and the dip at Ellingson's mine is N., while in the road in sec. 7, T. 114 N., R. 37 W., the strike is NE.-SW., with a vertical dip. Some variation from the above strikes and dips was seen at other places.

In microscopical characters this rock is interesting. There is little quartz present, and what was seen gave every evidence of secondary origin. It occurs in the areas of pyroxenic alteration to amphibole and where biotite has been formed. There are also bands of quartz grains around the borders of the frayed-out feldspars in the altered portions of the rock. The feldspars themselves are largely microcline and partly a plagioclase of low extinction, regarded as anorthoclase or albite, with an occasional area of labradorite habit. In quantity the feldspar varies greatly, some hand specimens showing but a small proportion, while others are made up almost wholly of the feldspars and a few scattering grains of quartz. The pegmatitic samples show the feldspathic constituent to be chiefly microcline, which carries numerous intergrowths of albite and occasional inclusions of some variety of higher extinction well toward the anorthite end of the series.

The augite is green in color, weak in dichroism, and rather strongly cleaved. It possesses the physical characters of the ordinary variety

of the mineral. One crystal, more than an inch through, measured very nearly 87° and 93° on its prismatic angles. The usual extinction angle on prismatic cleavages was 39° to 43° . Alteration has begun in many places, and green hornblende is the first resultant product. Its first appearance was in small fresh areas in the midst of the augite individuals or in similar condition around their borders (sp. 5372, 5374, 5748, 5751), followed in later changes by well-defined individuals (sp. 5749, 5750) in which all the characters of common green hornblende are well displayed.

Biotite plays a somewhat important rôle in this series of specimens. It is found in large, well-marked folia, even in those sections where hornblende is just appearing along the edges of the augite individuals (sp. 5372, 5751). The relation of the biotite to the augite in such sections as were made of specimen 5748, where small areas of biotite lie in the midst of large augites, and its entire absence in other specimens where hornblende is strongly developed, give strong suggestion of its being a secondary mineral, and that its host is augite, and possibly in places hornblende also.

Sphene and epidote are both present in small quantities. The former is clear cut and wedge-shaped where the sections are in proper position. The favorite situation of the sphene is the circumference of the hornblende nests where associated with granules of quartz. It forms the boundary zone between these nests and the feldspars which make up the mass of the rock. Apatite is seen in the usual well-defined crystals, some of them attaining considerable size.

It is difficult to determine the relationship of this rock to the ordinary hornblende-biotite-gneisses around. Nowhere could the contact of the two be seen; yet the abrupt change in texture and mineral composition shows them to be widely different rocks. This augitic rock does not show evidence of being ordinary inclusions in the gneisses, like the masses which Mr. A. H. Elftman has found in the granites of northeastern Minnesota,¹ nor like those which the writer has seen around Rhineland, Wisconsin.² Regarding the resemblances of the latter rock, Professor Van Hise noted these points:

The microcline is very plentiful and the feldspars in extinction angles and species are the same as in the granites [of central Minnesota]. The areas of biotite, augite, and hornblende are large and numerous, the three minerals together composing more than one-half of the rock (sp. 5374). The biotite occurs in large brown flakes, exactly as in the hornblende-biotite-granites. As in these, the hornblende is secondary to the augite, but this specimen differs from any of them in the great relative abundance of augite, not more than one-fourth or one-fifth of this mineral having altered to hornblende. If this alteration from augite to hornblende had proceeded further and a portion of the feldspar had been replaced by quartz, this rock would have become a hornblende-biotite-granite.³

¹ Preliminary report of field work during 1893 in northeastern Minnesota, by Arthur Hugo Elftman: 2d Ann. Rept. Geol. Nat. Hist. Survey Minnesota, 1894, p. 157.

² Geological excursion into central Wisconsin, by C. W. Hall: Bull. Minn. Acad. Nat. Sci., Vol. III, No. 2, 1891, p. 259.

³ Van Hise, unpublished manuscript.

The foregoing very accurately expresses the conditions, and the writer's opinion is that here is a group of rocks which bears strong evidence of being a mass erupted under the same conditions, and possibly at the same time, as the great granite masses of central Minnesota, which have their typical development around St. Cloud, Sauk Rapids, and Watab.

HORNBLLENDE-BIOTITE-GNEISSES.

With no perceptible change in the conditions and occurrence, the granite-gneisses of sec. 13, T. 112 N., R. 34 W., and the chlorite-gneisses of sec. 10, T. 112 N., R. 34 W., give place to the sharply contorted hornblendic biotite-gneisses of Morton and Beaver Falls. That the rocks around these two villages reach a considerable height above the present level of the river has already been pointed out in Chapter III. They stand nearly to the height of the prairies on both sides of the river valley. Indeed, this prominent position of the knobs of contorted gneiss can be seen in many places; a few miles above Redwood Falls, on the south side of the Minnesota; in the gorge of the Redwood River at and below Redwood Falls; on both sides of the Minnesota River around Vicksburg; at Minnesota Falls; at Granite Falls; and in the bottoms below Montevideo. The prairie exposures located on Pl. XV are all of this mineral type. The sharp contortion prevailing in certain localities locally obscures the strike and dip phenomena. In spite of this obscurity the general NE.-SW. trend of the pre-Cambrian formations across this portion of the State can not be doubted, nor can the series of crustal waves whose crests appear several times between New Ulm and Ortonville. In many places the hornblende-biotite-gneisses are very fresh. Elsewhere there is complete obliteration of all the normal characters of a gneissic rock, save perhaps in the lamination, through the complicated alteration process which the rocks have undergone. The two extremes of the series, the fresh and the completely altered, as well as every intermediate stage, can be seen where the Pacific division of the Minneapolis and St. Louis Railroad crosses the Minnesota Valley from the prairies of the north side to those of the south side of the river. This is along the south side of T. 113 N., Rs. 34 and 35 W. In the quarries and railway cuts at Morton occur some of the freshest exposures of the valley, or, for that matter, of the whole Northwest, and in the Birch Cooley Gorge, only $1\frac{1}{2}$ miles away, can be seen equally fine and typical examples of the very extreme of alteration. Within a radius of 4 miles of Morton every intermediate phase of alteration can be seen. These phases have been considered in another place, and here only the mineral and physical characters of the normal gneiss will be discussed.

MORTON AREA.

In the quarries and railroad cut at Morton were found the exposures of freshest and apparently least-altered gneiss seen in this portion of the valley. Fig. 5 (p. 28) shows the contorted condition, with schistose

intrusions, and lenticular inclusions of coarser and scarcely laminated material. Pl. XVI, *B*, shows the mineral lamination of the rock as seen in the natural coarseness at the Morton quarries. The general color is dark gray, due to the light-pink hue of the feldspar and the large proportion of biotite. The arrangement and the thickness of the mineral bands vary considerably. Lenticular masses are frequent, composed largely of biotite, hornblende, and quartz. These are, as a rule, schistose and of medium grain. Less frequently the inclusions are decidedly hornblendic, actinolite being a prominent constituent. Individual areas within these inclusions shade off from green to white. They extinguish at angles of from 9° to 17° from the position parallel to the principal cleavage. Such actinolic inclusions are not large, nor were they observed near the surface. It was in the deepest portions of the quarry that the specimens were taken (sp. 5737). Scarcely any mineral save hornblende is present in these lenses.

The coarser pegmatitic inclusions, consisting chiefly of orthoclase and microcline, are more frequent in some places than in others; for instance, at the railroad cut at the bank of the river they abound, while in the quarry some rods away they are rare. The bands of the normal foliated gneiss in places abut directly against these pegmatitic masses; again they wind around them and conform to their shape. Still elsewhere the bands fault and continue from a point some little distance, even 2 or 3 inches, away. The concretions of biotite are as uncertain and irregular in their distribution as are the pegmatitic masses. They are seldom over three-fourths of an inch across and carry rather large folia of biotite and a comparatively small proportion of other mineral constituents. The general direction of the laminae immediately around Morton village is E.-W., bending to the south and north of this direction sufficiently to give a NE.-SW. trend to the formation of the area as a whole. The dip is, on the whole, northerly and varies from the horizontal to 50° and more.

The specimens gathered from the bottom of the Morton quarry and at as great a distance from the joints as it was possible to secure them show a less degree of alteration than do those taken from near the surface. The difference is not so much in the freshness of the constituent minerals as in the predominance among the latter of microcline and finely crystalline secondary quartz. As representatives of the freshest material, specimens 5734 and 5735 will serve. In these specimens the feldspars are orthoclase, microcline, and a plagioclase, in nearly equal proportions. The plagioclase is near the albite-oligoclase type, with its inconspicuous twinning and low extinction angles. The orthoclase and plagioclase seem to be more corroded about their borders than are the microclines. The result of this corrosion seems to be finely crystalline quartz, with a few minute, fresh microcline and orthoclase areas, which are brightly polarizing and free from inclusions. The larger, and perhaps primary, microcline areas contain less of the microcrystalline

accessories of decay and alteration—largely kaolinic material—than do the other feldspars named.

Biotite is the chief bisilicate mineral present. It occurs in isolated folia rather than in the segregated form seen in the gabbroid series of the valley. As a rule, the individuals are comparatively free from impurities, yet now and then a light-brown mineral of either clustered or reticulated distribution, thought to be rutile, is seen. This mineral is oftener, however, an impurity in the hornblendic constituent than in the biotite. Aside from these two, the rutile and the hornblendic mineral, accessories are unusually rare.

Specimens 5210, 5211, and 5212 show the condition of the rock at or near the surface. The proportion of secondary minerals is much greater and their individuals are much larger than the corresponding minerals in specimens 5734 and 5735. The orthoclase and plagioclase feldspars are considerably corroded. The microcline individuals are fresh and free from inclusions. Their size is greater than that of the other varieties of feldspar. They are rough and uneven on their borders, like the other feldspars. They contain inclusions of kaolinic material and small quantities of muscovite, as do the orthoclases, and in other ways they show evidences of alteration. Undulatory extinction is often seen. Biotite is the leading bisilicate constituent; indeed, it is practically the only one. The folia are small and sharply defined. As they lie beside each other they are bounded by even planes of contact. Inclusions are comparatively rare. The individuals are prone to segregate in clusters and bands. Not infrequently biotite inclusions occur in the feldspars, particularly the albite-oligoclase variety; indeed, they assume a fibrous condition, and appear between the twinning lamellæ.

Here and there a chloritic phase represents the bisilicate constituent, and rarely hornblende clusters are seen. The ordinary green variety of hornblende is the one present. It can not be determined that the deeper gneisses are of the usual hornblende-biotite type, although the analogy afforded by the valley as a whole gives strong reasons for such an assumption.

Pyrite is present in small quantities, and apatite is even more rarely seen. In addition to these two accessories, another is present, which at once attracts attention as thin sections are examined. It occurs in numerous circular areas, thickly studded with minute, dark, opaque spots. These circular areas are small, ranging between 0.075 and 0.250 mm. in diameter. Within them lie thickly clustered crystal granules of various shapes, together with an enormous number of black, opaque, spherical granules. The individuals are all so small that it is extremely difficult to determine the species present, but feldspar, hornblende, and biotite can be named with much assurance. A quantity finely pulverized and tested with the magnet gave a generous supply of black magnetic grains. When these circular areas were first noted, it was thought

that they must have been formed through the action of substances derived from the decomposition of iron-sulphide crystals and crystalline granules distributed plentifully throughout the rock. The granitic character of the rock would facilitate the spherical habit which these bodies invariably possess. The several processes involved in such an alteration might be followed with some positiveness were it possible to prove the mineral identity of the several species distinguished.

In chemical composition the rock as a whole shows a more basic character than the less foliated gneisses and granite-gneisses in other portions of the valley. This character will be seen by comparing the analysis below with the analysis of the Ortonville granite-gneiss, on page 63. A. D. Meeds, of the University of Minnesota, analyzed an average sample taken from the Morton quarry and reported as follows:

Analysis of the hornblende-biotite-gneiss of Morton, Minnesota.

Constituent.	Per cent.
SiO ₂	63.61
Al ₂ O ₃	18.71
Fe ₂ O ₃	5.69
FeO.....	2.78
CaO.....	4.03
MgO.....	1.63
K ₂ O.....	2.49
Na ₂ O.....	1.68
H ₂ O.....	0.61
P ₂ O ₅	0.25
Total	99.48

BEAVER FALLS AND REDWOOD FALLS AREAS.

At Beaver Falls the conditions are almost identical with those at Morton and along the Birch Cooley. At Redwood Falls also the same is true so far as the rock is in a fresh condition. The occurrence of altered gneisses shows essentially the same conditions and phenomena in all three of the localities; thus they are all conspicuous for the succession of changes easily traced from the fresh to the kaolinic condition.

The small exposure of gneiss in the woods between the road and the Minnesota River, along the bottoms between Beaver Creek and the Redwood Falls ferry, is worthy of notice. Specimen 5252 is from this locality. The knobs of rock extend in a direction N. 60° E. The largest mass of the group is only 175 feet long and 15 feet high. The prevailing color of the rock is red. While in general the appearance is that of a very fresh, firm gneiss, almost entirely unaffected by the kaolinization process which so conspicuously marks the gneissic exposures in the near vicinity, particularly along the banks of Beaver Creek, yet the entire mass is so shattered that not even a 3 by 4 inch hand specimen could anywhere be taken. The texture is medium, with

a slight tendency to porphyritic condition. It has a sharp angular fracture. The porphyritic condition disappears under the microscope. It is due to the cleavage of the scattered remnants of the feldspar individuals. Excepting these remnants, the entire mass is composed of secondary minerals. The quartz is entirely secondary and lies in minute, brightly polarizing, limpid areas. The few feldspar cores remaining are of the orthoclase and the anorthoclase-albite types. They are spherical or elliptical in shape, ragged, corroded on their margins, and somewhat altered within. The clustered and isolated secondary individuals are brightly polarizing, and represent microcline in large proportion, with scattering grains of andesine-labradorite.

The quantity of basic constituents is extremely small. No hornblende was seen. The biotite occurs in minute, sparsely scattered clusters of fibrous material, which generally disclose the radial extinction so frequently characteristic of chlorite. Magnetite is plentiful in minute, clustered, rounded granules, showing every evidence of secondary origin. Frequently around these clusters is red hematite. Some other accessories were noticed, particularly apatite, but they seem to cut no figure in the mineral composition of the rock, and are in all cases apparently the results of alteration processes.

The fractured condition of these exposures affords many narrow fissures disposed in every direction through the rock. Along the walls of these fissures can be seen numberless crystals of quartz and the several feldspars. In size they are small, rarely reaching a millimeter across. They proved too minute for microscopical determination, and too few were gathered to admit of a chemical analysis.

In all essential particulars these occurrences are identical with those noted down the river at La Framboise's farm, where the microcline crystals were 3 to 4 inches in size.

The altered gneisses mentioned as occurring around Beaver Falls and Morton (see pp. 29, 32, 59) show, in chemical composition, considerable variation from the fresh phases of the rock. The following analysis was made by A. D. Meeds:

Analysis of impure kaolin (sp. 5220) from Birch Cooley, Minnesota.

Constituent.	Per cent.
SiO ₂	41.71
Al ₂ O ₃	34.61
Fe ₂ O ₃	4.58
FeO	6.88
CaO	1.16
MgO	0.22
Na ₂ O	0.11
K ₂ O	Trace.
H ₂ O	12.69
Total	101.96

CHAPTER V.

GABBRO-SCHISTS.

GENERAL CONSIDERATIONS.

Throughout the valley, intermingled with the normal acidic gneisses, are numerous occurrences of gabbro-schists, varying considerably both in mineral constituents and in chemical composition.

The salient microscopic characters of the gabbro-schists as a whole are the following: A dark-green to black color, due to the abundance of hornblende; a schistose structure, dependent in large degree on the parallel arrangement of the hornblende individuals; a freshness of appearance, due in part to the unweathered condition of the rock, and in part, no doubt, to the fact that the hornblendic constituent and some others are of a secondary origin.

Wherever these schists occur they exhibit a pronounced foliated structure, which in some places represents a gneissic rock and in others a schistose one. This difference seems to arise from the varying proportion of the feldspathic constituents on the one hand and the condition of the amphibole-pyroxene constituents on the other. Wherever the former predominate the amphibole-pyroxene minerals are segregated in bands, precisely as hornblende and biotite mark off the darker-colored laminae in the normal gneisses, and where the feldspars diminish in quantity the rock becomes more and more homogeneous in constitution until a normal hornblende-augite-schist appears. This is the case in several localities, notably south of Odessa, in sec. 9, T. 120 N., R. 45 W., at several places around Minnesota Falls and Granite Falls, and in sec. 15, T. 112 N., R. 34 W. In dip and strike these rocks always appear conformable with the normal gneisses. While the normal gneisses display in places great contortion and diversity of direction, the gabbro-schist series, as these amphibole-pyroxene-bearing rocks may be called, are to a great extent free from that irregularity.

Structurally these rocks are subject to all the conditions of jointing, faulting, and vein carrying which obtain among the gneissic rocks. They are broken through by dikes and are apparently as little altered by the contact as are the gneissic rocks.

At several localities visited the gabbro-schists show no marked evidence of schistosity. Elsewhere, and generally, the foliated character is the most prominent feature of the rock. Thus the gabbro-schists appear massive in places at the "gold mine" in Minnesota Falls.

few paces in either direction from the quartz vein at this place the schistose structure appears with a less number of garnets than lie beside the quartz vein. The schistose gabbro in places becomes porphyritic, as do the gneisses, and even more conspicuously so than do the latter rocks. One place in particular is of interest in this connection. Feldspar crystals of the plagioclastic type, 3 or 4 inches across, are frequent. This spot is in Granite Falls, the precise location being 1,750 paces north and 250 paces west of the SE. corner of sec. 32, T. 116 N., R. 39 W. The area referred to is 25 paces long by 20 paces wide, and is only a few paces from a large diabase dike, which extends from the river toward the southwest across a hill that is a conspicuous topographic feature in the western part of the city of Granite Falls. No relation could be seen between the schist and the dike. At this same locality the schist has been shattered and welded by innumerable quartz and feldspar veins. These veins, which are of almost paper thinness, extend through the rock and cross one another in every conceivable direction.

Occasionally one sees the peculiar segregations of feldspathic material characteristic of the "augen-gneiss" of the German geologists. This, however, is a character somewhat restricted to the ordinary acidic gneisses of the valley.

Considerable diversity in texture can be seen. Although the ordinary condition is that of a medium-grained rock, it varies on the one hand to a very coarse schist or gneiss, and on the other to an extremely fine-textured one. A crushing of the rock and the subsequent welding together through infiltration has produced in places a peculiar shattering. This phenomenon appears in the gneisses also. Texture seems in no way to be associated with or dependent upon the present mineral composition of these rocks. Occasionally, when a pyroxenic constituent breaks up into complexes or becomes changed into hornblende, as the case may be, a semblance of fineness of texture is given. In such cases the feldspars in their unchanged size maintain the general coarseness of the rock, even when they have undergone a profound molecular change or a complete transformation from one feldspathic type to another; and the infiltrations of quartz, when this process has been carried on to an appreciable extent, exhibit similar large areas. As compared with those of other districts, the gabbros of the Minnesota River Valley possess a fine texture. They are much finer than the same rock which lies in enormous sheets at the base of the Keweenaw eruptives in northern Minnesota; they are finer than the gabbros of Maryland which Williams has described,¹ and of which that author has kindly furnished hand specimens; and they are of a far more compact and finer texture than the Delaware gabbros described by Chester.²

¹ The gabbros and associated hornblende rocks occurring in the neighborhood of Baltimore, Md., by G. H. Williams: Bull. U. S. Geol. Survey No. 28, 1886, Chapters II and III.

² The gabbros and associated rocks in Delaware, by F. D. Chester: Bull. U. S. Geol. Survey No. 59, 1890, pp. 10-19.

In comparing the Minnesota Valley rocks with others of similar mineralogical composition the most noticeable features are the fresh, firm, bright condition of these rocks and their general laminated character. All weathered portions have been removed through glacial erosion, and a remarkable freshness is noticed at once on removing the outer film of recent decay where exposure to the air and storms has been constant. But the distinctive characters of igneous rocks are not seen here as they prevail in the gabbros of Delaware, described by Chester;¹ in those in the neighborhood of Baltimore, Maryland;² in those of New Hampshire, described by Hawes;³ in those of Wisconsin,⁴ described by the writer; in those of northeastern Minnesota;⁵ in those of western Scotland and neighboring islands, described by Judd;⁶ in those of Saxony, described by Lehmann;⁷ and in those of the west coast of Africa, described by Lenz.⁸ Yet, so far as mineral composition is concerned, every attribute of a typical ancient, basic, igneous rock is represented.

Arranged according to their mineral composition, there are several varieties in this gabbro-schist series. Originally there were probably but two—a hypersthene-bearing and a hypersthene-free gabbro—and these two approach each other by a scarcely perceptible gradation. All other modifications are subsequent. These alterations consist of the complete disappearance of the pyroxenic constituents and of the substitution in their place of hornblende and biotite. Every step in this substitution can be seen in the series of rock samples gathered. Meanwhile the plagioclases are as fresh in the most altered as in the comparatively unaltered members of the series.

So far as the field observations could show, there was no difference whatever in the environment of the two original types. The hypersthene-bearing rocks show the same general external features and have precisely the same relations to the gneisses and diabases associated with them as do the exposures which carry no hypersthene. Indeed, this division into types may have no ground in fact. It is possible, indeed probable, that this classification is based upon mere accident. Additional slides made from the same localities may show an entire absence of hypersthene where the slides examined show it to be present, and areas of the mineral* may be disclosed where now it is considered absent.

¹The gabbros and associated rocks in Delaware, by F. D. Chester: Bull. U. S. Geol. Survey No. 59, 1890, p. 41 et seq.

²G. H. Williams, *ibid.*, p. 11.

³The geology and lithology of New Hampshire, by G. W. Hawes: The Geology of New Hampshire, Vol. III, Part IV, 1878, p. 165 et seq.

⁴Notes of a geological excursion into central Wisconsin, by C. W. Hall: Bull. Minn. Acad. Nat. Sci., Vol. III, No. 2, 1891, p. 250.

⁵Preliminary description of the peridotites, gabbros, diabases, and andesytes of Minnesota, by M. E. Wadsworth: Bull. Geol. Nat. Hist. Survey Minnesota, No. 2, 1887, pp. 47-69.

⁶On the Tertiary and older peridotites of Scotland: Quart. Jour. Geol. Soc. London, Vol. XLI, 1885, p. 358.

⁷Untersuchungen über die Entstehung der Altkrystallinischen Schiefergesteine, by Dr. J. Lehmann, Bonn, 1884, pp. 191, 192.

⁸Gabbro von der Westküste Afrikas, by O. Lenz: Verhandl. K.-k. geol. Reichsanstalt, Wien, 1878, p. 52.

MINERAL CONSTITUENTS OF THE GABBRO-SCHISTS.

The mineral constituents of the gabbro-schists are labradorite, pyroxene, both the orthorhombic and the monoclinic, with its alteration products, and hornblende, magnetite, and various accessory minerals—pyrite, apatite, titanite iron, garnet, and quartz.

The feldspathic constituent is the basic type, usually near to labradorite in its extinction angle and in its polysynthetic twinning. This last character is always present and distinctly visible, except when the sections are cut parallel to b (010), or in rare cases where alteration has obscured the lamination. In places the feldspars present some inclusions of foreign particles; but as a rule they are singularly free from impurities, save where these are the result of alteration. Such alteration products are chiefly kaolin and smaller quantities of epidote. The feldspars do not occur in lathlike forms. Were there no other means of distinguishing the rock from the dike bodies, this would prove an unerring one. The areas of this mineral show little difference in breadth and length.

Normal augite generally appears in thin sections. The exceptions are the hypersthene-gabbros soon to be described. It usually possesses the light-brown color characteristic of the rock-forming condition of this mineral, but in some places it varies to a pink, and only in polarized light can it be distinguished with certainty from the common garnet of the valley. Its cleavage is, as a rule, very distinct. Its alteration phenomena are of the usual kinds. Occasionally, however, the augite is badly altered to hornblende; in fact, hornblende has in places completely replaced its host.

Diallage, which Zirkel,¹ Rosenbusch,² von Lasaulx,³ von Gümbel,⁴ Naumann,⁵ and others have regarded as an essential constituent, is always present in the Minnesota Valley gabbro-schists. It has in all cases undergone alteration, but the several stages of this change exhibit marked differences, described later, from those characterizing the hypersthene. In the diallage the alteration is to hornblende, but the process goes on in the middle of the crystal grains as well as along cleavages and fractures. A molecular change is seen. Pl. XIX, A, to some extent indicates this process. The fresh-looking diallage alters, molecule by molecule, to the dichroic green hornblende. In places the hornblende granules—or, as they more usually are, folia—have attained considerable size, while in other places they are so minute as to require an

¹Gabbro von der Westküste Afrikas, by O. Lenz: Verhandl. K.-k. geol. Reichsanstalt, Wien, 1878, Vol. II, p. 110: also Mikroskopische Beschaffenheit der Mineralien und Gesteine, by Dr. Ferdinand Zirkel, 1873, p. 441.

²Mikroskopische Physiographie der Mineralien und Gesteine, by H. Rosenbusch: Zweite Auflage, 1886, p. 132. Compare Microscopical Physiography of the Rock-Making Minerals, by H. Rosenbusch: Iddings's translation, New York, 1888, p. 239. "In the Archean rocks diallage is seldom met with. It is here confined * * * to certain amphibolites which may be considered as probably dynamometamorphic gabbros."

³Elemente der Petrographie, by Dr. A. von Lasaulx, Bonn, 1875, p. 310.

⁴Geologie von Bayern, by Dr. K. Wilhelm von Gümbel: Erster Theil, Grundsätze der Geologie, p. 129.

⁵Lehrbuch der Geognosie, by Dr. Carl Friederich Naumann, Vol. I, 1858, p. 573.

immersion lens to separate them from the diallagic matrix in which they are embedded.

The peculiar double cleavage of diallage is not seen on every granule of monoclinic pyroxene. Very likely many individuals, through the faintness of the secondary lines in the direction $\propto P \bar{\alpha}$, may be regarded as the crystallographically intermediate forms between normal augite and typical diallage.

In a few places, as has already been anticipated, orthorhombic pyroxene, hypersthene, appears, but never to the exclusion of the monoclinic pyroxenes augite and diallage. In extent of alteration the hypersthene always takes precedence over all others. Rarely is an individual found without a strongly marked corrosion along its cleavages or the fractures which it carries. This alteration continues until the individuals are completely obliterated. The change is accompanied by the formation of areas of magnetite and fibers and broader bands of green hornblende. Other minerals result, but they are less in quantity and of minor mineralogical importance.

Both pyroxenes and feldspars are granular, neither seeming to play the part of matrix, but both being hypidiomorphic in their derivation and form. In the dike rocks, on the other hand, the augite is wedged in between the well-formed crystals of the feldspar constituent, or, in broad areas, it serves as a matrix in which the lathlike feldspar crystals have developed a very perfect form. Pl. XXV, A and B, show these differences very clearly.

The distinction here made between gabbros and diabases was first hinted at by Zirkel in 1866, when he described the labradorite of diabases as forming tabular crystalline individuals of distinct cleavage, varying color, and showing the characteristic twinning striæ of the basal face, while the labradorite of the gabbros exhibits distinct twinning striæ and occurs in coarse crystalline grains.¹ The pyroxenic constituent was, according to Zirkel, augite in diabase and diallage in gabbro.²

Magnetite, which is an almost universal constituent of the gabbroschists, in places occurs in angular crystallized areas, seldom in single crystals but more commonly in rounded masses of very small size. It rarely shows traces of alteration into hematitic granules. That magnetite is a primary constituent of these rocks is by no means certain, so far as investigations now show. There is little doubt of its secondary nature where the hypersthene is altered; on the other hand, in northeastern Minnesota primary titaniferous magnetite in large masses occurs in the gabbros of Keweenaw age. It is probable

¹ *Lehrbuch der Petrographie*, Dr. Ferdinand Zirkel, Bonn, 1866, Vol. II, p. 78. "Der Labradorit bildet krystallinische tafelförmige Parteen von deutlicher Spaltbarkeit und weisser, graulichweisser oder grünlichweisser Farbe; sind die Krystalle noch frisch, so gelingt es oft die charakteristische Zwillingsstreifung auf der basischen Spaltungsflächen wahrzunehmen."

² *Ibid.*, Vol. II, p. 110. "Der Labradorit ist glänzend weisslichgrau oder etwas ins bläulichviolette und besitzt in groben krystallinischen Körnern deutliche Zwillingsstreifung."

that a portion of the opaque material which is visible in every slide is ilmenite or some closely related species, since titanite acid seems to be a common constituent of the gabbro-schists of Minnesota.

Accessory minerals occur everywhere in the schistose gabbros. The leading ones are pyrite, apatite, garnets, and quartz. Others appear as the modifying circumstances vary. Titanite iron, or menaccanite, doubtless occurs in small individuals in some specimens. Somewhat rarely the pyritic accessory has the golden-yellow color of chalcopyrite. The garnet and quartz are not contact minerals, as Teall seems to regard them,¹ but rather accessories and alteration products, to be found wherever alteration appears, whether brought about by weathering or by the deeper-seated change of metamorphism. The garnets are undoubtedly present in all contact alterations also, and perhaps have a still wider distribution than either weathering or deeper-seated alteration alone would produce. The quartz is regarded as partly an infiltration product and partly a by-product of the alteration of the augite to hornblende or biotite, or, as is often the case, to both.

Among the minerals which may be regarded as purely resultant products of decomposition, hornblende should certainly occupy the first place. Yet it is not safe to assume that all the hornblende is of this nature, for there is no sure means of determining the primary or the secondary origin of portions of this material. There is no doubt of the secondary development of by far the larger portion. It lies around the areas of pyroxene in such a manner as to preclude all doubt of its origin; it takes the place of pyroxene where such areas have become completely changed to a finely granular, bright-green, hornblendic segregation; and, finally, it shows a fibrous condition and a semigranular state within the feldspar areas, thus pointing to the breaking up of many individuals of this mineral. It may be said, in passing, that the parallel growth of augite and its resulting hornblende is very rarely seen; perhaps a half dozen sections were noted in the examination of these rocks which show this parallel position of host and product.

Passing to matters of more detail in the study of these gabbro-schists and to points which possess a somewhat local interest, we shall first describe the hypersthene-bearing gabbros; secondly, the hypersthene-free gabbros, and lastly the pyroxene-free gabbros or gabbro-diorites.

HYPERSTHENE-BEARING GABBRO-SCHISTS.

LA FRAMBOISE AREA.

A few paces from the river bank at the old La Framboise landing, in sec. 22, T. 111 N., R. 32 W., a mass of gabbro (sp. 5191, 5724) lies in the midst of the gneisses, constituting the large series of exposures in secs. 15, 16, 21, and 22 of this township. The relations of the gabbro

¹British Petrography, by J. J. H. Teall, London, 1888, pp. 383, 385.

to the gneisses could not with certainty be made out, though, as will be seen later, the gabbro is probably intrusive in the gneisses. There is a sharp contact line where the two are seen side by side, which, however, can be followed a short distance only, owing to the covered condition of the rocks.

The gabbro here shows little of that schistose character almost everywhere present in the valley. The texture is medium, with perceptible tendency to porphyritic habit; to the unaided eye it is decidedly granular. The color in the mass is dark, a dark-green ground tone prevailing, with numerous white flecks which disclose the presence of feldspar, since they display, on some of the larger individuals, the polysynthetic twinning of the plagioclases. The dark-green grains show clearly the perfect cleavage of hornblende. The remaining constituents are not easily recognized with the unaided eye nor, in some cases, even with the microscope.

The rock is superficially weathered. The outer coating is of a reddish or dirty gray color, due to the alteration of the constituent minerals. When this coating—nowhere more than one-eighth to one-fourth of an inch thick—is removed, the rock is very fresh and sparkling. The green color just noted, and a tendency to crush to a light-gray powder under the hammer, suggest, however, that an alteration has really taken place and gone farther than the appearance of the rock would indicate. On account of the sharp contrast shown between this rock and the augite-gneiss in which it lies, and the general aspect which the rock carries of an eruptive species, the eruption of this mass into the gneiss can not well be doubted. The naked eye distinguishes a hypidiomorphic habit of the constituent minerals and the granitoid character of the gabbro rather than the ophitic or porphyritic character of a diabase.

The leading feldspars in this gabbro are near the labradorite-anorthite end of the plagioclase series. In shape the individuals are broad rather than lathlike. Twinning striae are sharp and clear. The extinction angle on M is frequently 40° and more. Other areas cut on the pinacoidal plane give the extinction angle characteristic of mixtures with the formula ab_1an_8 to ab_1an_{12} ; in other words, they extinguish around 30° . Undulous extinction occurs in a few individuals, particularly those cut in such direction that the twinning lamellae do not appear, or if present are very far apart. This, therefore, is not a strong character of the rock.

In the several thin sections prepared there is little material which can be regarded as an alteration product from the feldspars. Now and then clusters of secondary grains and small crystals can be seen, but usually the inclusions within the feldspars are easily recognized as a pyroxene or hornblende. Microcline and plagioclases of low extinction, pointing to a high percentage of soda, were not noticed either as primary or secondary constituents.

The pyroxenes of this gabbro are two, and probably three, in number—hypersthene, diallage, and probably augite.

Hypersthene composes more than half of the bisilicate constituents of this gabbro. The characteristic dichroism of this mineral is sharply shown, as is also the parallel extinction of the grains. It is in the neighborhood of the hypersthene area that the grains and aggregates of hornblende are chiefly seen. Some of the hornblende individuals are isolated, and thus their genetic relationship to the hypersthene is obscured. It is possible that some individuals are not thus derived; yet the varying quantitative proportion of the mineral and the fact that its derivation from hypersthene can be clearly proved at other localities in the valley are the grounds for assuming such origin at this locality. There are no characters displayed by the hornblende so different from those at other exposures as to require further mention.

Diallage has suffered greatly through alteration. Grains have become diminished in size by the changing of their borders or interior portions, or both, into hornblende. The external characters of augite and diallage, save in one or two respects, are so similar that a sharp distinction between these two pyroxenes was not made. Where the characteristic cleavage of diallage was seen the identification of this mineral was considered sufficient. Many grains with a rather high extinction angle are entirely lacking in this character. The presence of augite is therefore assumed.

Pyrite is present in a few isolated and segregated grains.

WABASHA CREEK AREA.

Passing to the next district up the river from La Framboise's, we find, in sec. 15, T. 112 N., R. 34 W., a small exposure of hornblendic gabbro-schist (sp. 5399). Its lamination is not sharp and clear. Only a few paces to the north, and again a short distance to the south, stands a highly acidic gneiss in moderately high exposures, decidedly abrupt on the north side, and weathering in large, concentrically breaking blocks to a crumbling, dirty mass of feldspar chips. The direction of the schist exposure is NW.-SE., and the dip is apparently NE. at a medium angle.

In the gabbro-schist the individuals of feldspar vary greatly in size. Occasionally those of unusually large size are seen, but more frequently a finely granular condition prevails. The labradorite type abounds. A general freshness characterizes this mineral. Even where individuals are fractured and the joints have become filled with vein-like material there is no trace of decomposition along the margins. The twinning striae are very strong. While this is true of most of the feldspars, there are individuals showing decided marks of disintegration. The product is a mass of finely crystalline, brightly polarizing, transparent material. Often in the altered individuals a fibrous radial arrangement of the decomposition product can be seen under crossed nicols. It is apparently a single mineral rather than a cluster of different species. This appearance leads to the opinion that the

process is a zeolitization of the feldspar rather than a saussuritization, since this process develops an aggregate of distinct minerals.¹

The diallage is well marked with the usual characters of that mineral. In some individuals it has undergone alteration to hornblende to such an extent as to impart a green color to the residue of the decomposing grains. The double cleavage and the parting bands are not always distinctly seen; therefore some of the pyroxene may be assumed to be augite.²

Hypersthene occurs both in nests and in isolated grains. Where the latter appear they seem to have absolutely no crystal form; a decidedly granular condition is always present, and the ordinary prismatic cleavage is frequently indistinct. Where the hypersthene is segregated, several grains may lie side by side, having precisely the same plane of extinction and showing the same ragged and corroded outlines toward the feldspars as do the isolated individuals. Many hypersthene grains are completely altered into hornblende and some associated mineral, which may be ferrite; others are only partially altered. They carry within them small individuals exhibiting the cleavage and optic extinction of hornblende. Being considerably shattered, alteration first seizes the hypersthene, producing along the cracks fibrous hornblende, which usually lies parallel with the cleavage striæ of the host. Around the borders of the changing hypersthene individuals, lying as though expelled by the alteration process from the midst of the hypersthene material and the resulting hornblende, is a granular mineral somewhat transparent and of light-brown color. Its minute size prevented further identification.

More rarely yet—as a rule, in the vicinity of these alterations—are larger masses of magnetite. Clusters and single grains exhibit the usual characters.

This locality further shows an interesting vein formation, evidently resulting from the joint action of crushing and mineral alteration. The mineral playing the leading rôle in the vein filling is hornblende. The anastomosing of the hornblendic material is marked, and is seen in Pl. XXIII, A. Crystal grains are broken, and between their fragments the minute leaves of hornblendic matter are seen, or grains are pressed apart and the interspace is packed full of the vein material. These veins were seen only in the much-altered gabbro-schists.

MINNESOTA FALLS AND GRANITE FALLS AREAS.

Around Minnesota Falls and Granite Falls there is a remarkable development of the hypersthene-bearing gabbros. One approaches a conspicuous belt of these rocks in ascending the river on the north side. The chief rock in secs. 11 and 14, T. 115 N., R. 39 W., is a gabbro. In the southeast corner of sec. 13 stands an area of well-banded gneiss

¹ Ueber Saussurit, by A. Cathrein: *Zeitschr. für Kryst. und Min.*, Vol. VII, 1883, p. 248.

² *British Petrography*, by J. J. H. Teall, London, 1888, p. 132.

150 paces in extent which exhibits patches of coarse veinlike material. This gneiss is conspicuous for its small content of bisilicate constituents, its fresh microcline, and the undulatory extinction of its quartz areas. Along the boundary between secs. 11 and 14 and thence northward to the river are many patches of a black, distinctly laminated, hornblendic hypersthene-gabbro. The strike of these exposures is about N. 80° E. Along their southern border the dip is southerly, in sec. 12 reaching as high as 80°, while in the southern part of sec. 11 it is considerably less. Along the northern side of this section, while the strike is nearly the same as farther south, the dip is zero.

Throughout this whole area—and it embraces all the rock south of the great bend in the Minnesota River at Minnesota Falls, just below the site of the old dam and mill—granitic veins or dikes are numerous. In places, as along the section line between secs. 11 and 14, the granitic material is parallel with the lamination of the gabbros, and here and elsewhere the coarse texture of the former, as well as its sharp color contrasts, mark it as a phase of rock formation quite distinct from the latter.

Everywhere the lamination of the dark-colored hypersthene-bearing gabbro-schists is sharp and clear. The alteration to hornblende on the part of the pyroxenes has been carried so far as to give hornblende the leading place among the basic constituents, both macroscopically and microscopically. This altered condition of the rocks remains the same northward to the high, ragged, half-covered masses on the Russell farm, SE. $\frac{1}{4}$ sec. 11, T. 115 N., R. 39 W. On this farm the rocks have a northerly dip of 20° or more, with little contortion and with little special modification, even where they are broken through by dikes. This unaltered condition in the proximity of dikes can be well seen around the spot 1,300 paces N. and 1,800 paces W., sec. 12, T. 115 N., R. 39 W., where a dike (sp. 5280) 20 feet wide cuts through this same bed of gabbro-schist that first crops out on Russell's farm. Here and there a lighter color prevails, on account of the increase in the amount of feldspar, and in places through the light pea-green color of the secondary hornblende. A good illustration of these lithologic conditions is seen at the spot just indicated, near the contact of the dike. The gabbro-schist (sp. 5278, 5279) is hypersthene-bearing. Locally this bisilicate constituent almost wholly changes, leaving a rock largely composed of labradorite-anorthite feldspar and the alteration products biotite and hornblende (sp. 5279). Elsewhere the hypersthene and its alteration product, hornblende, are present in normal force. The rock then becomes a good example of a partially altered hypersthene-gabbro (sp. 5278, sl. 2237), and represents an intermediate stage of rock alteration. (See Pl. XXI, A.)

Crossing the river into Yellow Medicine County and into the ruined village of Minnesota Falls, one sees comparatively no change in the characters of the rocks. Near the old dam, swept away in the flood of

1882, which carried away the village itself, there are both a reddish, highly siliceous gneiss (sp. 5236, 5237) and a gabbro-schist (sp. 5238). The contact of the two rocks is here as clearly marked as at La Framboise's place, already described. The distinct interbedding, or at least interpenetration, of the two rocks is seen at the river bank at the south end of the old dam. Both the gneiss and the gabbro-schist are here more schistose than at La Framboise's, yet, barring certain modifications incidental to such schistose condition, they are the same in mineral composition.

The monoclinic pyroxene of the gabbro-schist has sometimes a greenish tint, and again it appears very transparent and free from color save the usual brown tinge seen in the thicker sections. It is now mostly of the diallage type, though frequently the foliation partings are indistinct or even wholly absent. The individuals are granular, never exhibiting crystal planes. Hypersthene seems rather more abundant at Minnesota Falls than at La Framboise's, and alteration has not crept into the internal structure of the grains with such marked effect. In both places the mineral is characterized by rounded grains instead of extended areas more or less interrupted by other minerals. Hornblende is the common product of the alteration of the pyroxenes. It is almost wholly in the compact condition, usually dark brown in color, and somewhat strongly pleochroic. The grains vary in size from the most minute, embedded in the hypersthene areas, to those as large as the pyroxene individuals themselves. Cleavage is perfectly developed and is always seen in cross sections of the prisms. Inclusions are rather plentiful.

A few hundred paces southwest of the ruined village of Minnesota Falls the gabbro-schists again appear, as in the western part of the village, in long extended masses, standing in billowy rows of knobs. From these exposures northward into and entirely through the city of Granite Falls to the banks of the river in sec. 13, T. 116 N., R. 40 W., these rocks can be followed by a succession of outcrops. The prevailing schistose character, the NE.-SW. strike, the dip alternating between NW. and SE., the dark color, the predominance of hornblende, and the generally fresh, undecomposed condition of the rocks very generally prevail. Near the center of the city of Granite Falls, one or two blocks north of the court-house, an interesting curve in the strata was noted, and to the west, near the house of E. C. Shannon, lies an exposure of a highly porphyritic modification of the gabbro (sp. 5438). This spot has already been mentioned (Chap. III, p. 35). The porphyritic character of the rock is shown in Pl. XXIV, A.

The texture of the groundmass is rather fine. Its color is a gray black. A certain granular habit is due to the shape of the pyroxenes, augite and hypersthene, and their relations to the feldspars and subordinate constituents of the rock. The numerous cleaved surfaces of the several minerals give a decidedly glistening appearance to the surfaces

of fresh fractures. A good pocket lens reveals on some of these surfaces the twinning lamellæ of plagioclase feldspars, and on others the strong markings of hornblende. Where the surface has been exposed for a long time it becomes a dull black color. The process of color change follows steadily the removal of the feldspars, the first step being contemporaneous with the incipient kaolinization of these individuals. The kaolinization process continues until the feldspar grains and crystals are completely altered and the soluble products are removed. Broken specimens show upon their fresh fractures every stage of the alteration process between the surface phase, where the feldspars are wholly removed, and that other extreme, only about one-fourth of an inch below the surface, where scarcely a trace of kaolinization can be seen.

Quite thickly studding this dark, medium-grained, foliated ground-mass are the porphyritic feldspar crystals before mentioned. These crystals vary in size from a quarter of an inch to 3 inches in length, nearly all of them exceeding 1 inch (Pl. XXIV, A). Through the same kaolinization process characterizing the matrix the surfaces of these crystals exposed to the weather become white in color, dull in luster, and have been washed away until they lie in depressions below the general surface of the rock. Within they are of a greenish hue, owing to the presence of mineral accessories. Fresh surfaces show the perfect cleavage of feldspar, and when the cleavage is on a plane parallel with OP the striæ are very clear. These porphyritic feldspars are anorthite, as is seen from the extinction angle, 36° – 43° , and the chemical composition given below. Besides the cleavage, there is a conspicuous fracturing of the crystals corresponding to the fractured condition of the matrix. There are many inclusions in these anorthite crystals. Among those identified are magnetite, easily separated from the powdered mineral, augite, which extinguishes at angles varying between 45° and 55° , and, in fewer numbers, slender, minute crystals of hornblende. The specific gravity of anorthite is 2.715.

Within the matrix the usual minerals of a hornblende-hypersthene-gabbro are seen, viz, labradorite-anorthite feldspars, hornblende, augite, diallage and hypersthene with the accessories, magnetite, hematite, and chlorite. The hypersthene has the usual pleochroism; it occurs in grains wholly devoid of crystal planes and usually completely enwrapped with the pyroxene and its decomposition product, hornblende. The pyroxene is only to a small extent diallage. This is indicated by the almost universal absence of the characteristic diallagic parting, as well as in the high extinction angle shown by the individual grains. Indeed, the prevalent prismatic cleavage and an extinction angle generally ranging between 42° and 48° point to augite as the predominant pyroxenic species.

The hornblende is well distributed. It is partly uralitic and partly in well-cleaved, brown individuals. There is little doubt of its secondary origin in both modifications.

The specific gravity of the matrix is 3.015.

The chemical composition of the porphyritic hornblendic hypersthene-gabbro is of interest. Analyses were made of both the matrix and the labradorite-anorthite crystals by Prof. E. J. Babcock, of the University of North Dakota. The following are his results:

Analyses of porphyritic hornblendic hypersthene-gabbro from Granite Falls.

Constituent.	I.	II.
	<i>Per cent.</i>	<i>Per cent.</i>
SiO ₂ (silica)	47.43	46.40
Al ₂ O ₃ (alumina)	23.66	33.87
Fe ₂ O ₃ (ferric oxide)	13.06	0.34
CaO (lime)	11.21	14.73
MgO (magnesia)	3.15	0.04
K ₂ O (potash)	0.204	1.06
Na ₂ O (soda)	0.146	1.88
H ₂ O (water)	0.90	Trace.
Total	99.76	98.32

I. Porphyritic hornblendic hypersthene-gabbro (sp. 5438); the matrix rock, from which the anorthite crystals had been removed. Granite Falls.

II. Crystals of anorthite from the foregoing matrix.

From these results it is seen that the material agrees very closely in chemical composition with its physical characters as outlined on the preceding pages and determined by quite different methods. Attention may be called to the nearness in composition of the foregoing anorthite and that of the great gabbro masses of northeastern Minnesota, reported by Professor Irving,¹ and the Hammerfest (Norway) anorthite, quoted by Dana² from Pisani, first published in 1876.

Northwest of Granite Falls the gabbro lies in a gentle fold constituting the northern anticline of this locality. Along the south side of the river, from a little above the bridge and railway station, at present practically the middle of the city north and south, the road passes northwesterly in sight of almost continuous exposures of gabbro-schists for more than a mile. They are broken through in several places by the dikes which cross the valley in a NE.-SW. direction.

In this upper portion of the area the veins and feldspathic segregations are not so frequent as they are south of Minnesota Falls. Where they do appear they are a coarse mixture of green hornblende and labradorite or a closely related feldspar, with little, if any, quartz. The thin sections made show no appreciable quantity of this last-named mineral in the coarser segregations (sp. 5442). It is sufficient to say that they exhibit the lithological characters of the schists already noted lying along the south side of Granite Falls. The feld-

¹The copper-bearing rocks of Lake Superior, by R. D. Irving; Mon. U. S. Geol. Survey, Vol. V, 1883, p. 428.

²A System of Mineralogy, by E. S. Dana, 6th ed., 1892, p. 339.

spar has the high extinction angle of anorthite. This mineral is little altered. Frequently the individuals carry minute crystals of pyroxene and hornblende.

The pyroxenic constituents are hypersthene and augite. The former is more generally altered than the latter. The hypersthene grains are frequently surrounded by borders of hornblende. It is probable that it is the source of the greater portion of the latter mineral. The monoclinic pyroxene has generally the green color already noted for other exposures in this neighborhood. Very rarely is the diallagic cleavage $\propto P \infty$ (100) seen. Besides, the optical orientation determines the mineral to be augite rather than diallage, the extinction on the prismatic cleavage being between 47° and 50° . Hornblende is so abundant that the hand specimens were identified as hornblende-schist. The gabbroid character of the rock was not seen until the thin sections revealed the pyroxenic constituents.

On the north side of the river the gabbro-schists are finely developed at the bend of the river in Granite Falls, near the corner of secs. 33 and 34, T. 116 N., R. 39 W., and secs. 3 and 4, T. 116 N., R. 39 W., and thence northward to the Chicago, Milwaukee and St. Paul Railway station and the grain elevators of the city. Beyond these points gneissic rocks prevail to the northwest. They are of medium coarseness, distinct lamination, a prevailing dark color (which often, however, becomes somewhat lighter through the predominance of the feldspars), and a very fresh, vitreous surface along fractures. The strike of the laminae is NE.-SW., with a dip of 37° SE. Several dikes break through these rocks. One, near the Pillsbury elevator, is of considerable width.

As will be seen in the list of literature references (pp. 12-19), these rocks have long been known to the geologists and explorers of the Northwest, yet their general external characters have been cited in the vaguest and most cursory way. Featherstonhaugh briefly describes¹ these exposures as "resembling granite in every particular except its stratification," and in a subsequent work² he mentions masses of quasi-stratified granite, most of which "were red quartzose granite with a slight quantity of mica, but some were gneissoid." N. H. Winchell says³ that "At Granite Falls, as at Minnesota Falls, and all the way between, the rock in the valley is a schistose granite, almost a mica-schist, but it varies to a hard, gray granite that resembles that at St. Cloud both in color and composition." Upham⁴ gives a much more precise description of the prevailing rocks, "the gneisses," as he designates them, of this locality.

¹ Report of a geological reconnaissance made in 1835, etc., by G. W. Featherstonhaugh: Doc. 333, printed by order of the Senate, Washington, 1836, p. 28.

² A Canoe Voyage up the Minnaw Sotor, by G. W. Featherstonhaugh, 2 vols., Vol. I, London, 1847, pp. 333, 334.

³ The geology of the Minnesota Valley, by N. H. Winchell, State geologist, and S. F. Peckham, State chemist: Second Ann. Rept. Geol. Nat. Hist. Survey Minnesota, 1873, p. 170.

⁴ The geology of Yellow Medicine, Lyon, and Lincoln counties, by Warren Upham: Geol. Nat. Hist. Survey Minnesota, Vol. I, 1884, pp. 596, 597.

In microscopical characters they present a series from those exhibiting all the constituents in very fresh and apparently unchanged condition to those where many of the original constituents are completely obliterated through the metamorphic changes undergone. Such a series may be seen by comparing several of the accompanying illustrations. Pl. XVII, *B* (sp. 5335, sl. 2263), shows an unusually fresh hypersthene-gabbro taken from one of the small and somewhat isolated knobs southeast of Odessa. The feldspars are fresh and strongly polarizing, yet the pyroxenic constituent shows some traces of alteration. This specimen was taken to illustrate the freshest rock to be found at these exposures. Pl. XXI, *A*, shows (sp. 5278) a specimen taken south of the old dam in Minnesota Falls. The hypersthene at this locality is partly altered to a light-brown hornblende. The other constituent, a labradorite feldspar, is quite as fresh and unaltered as in the Odessa gabbro just mentioned. Magnetite is in the same physical condition and the same proportion in both. Again, in Pl. XXI, *B*, we see a gabbroid rock (sp. 5418), also from the southern part of Minnesota Falls, in which the pyroxenic constituents have entirely disappeared, having almost wholly altered into hornblende, with some addition to the amount of magnetite. The feldspars have also suffered corrosion to a very perceptible extent. The rock has thus become a diorite, a rock species which appears in several localities and in all cases under essentially the same physical conditions.

Everywhere about Granite Falls and Minnesota Falls the feldspar is sufficiently fresh to be identified, and with but two or three exceptions it is clear and brightly polarizing. The grains are of the typical hypidiomorphic structure. They contain few inclusions of any kind. The feldspar is of the labradorite type, but many variations from the normal extinction angle of this mineral were noted.

Augite, with its typical characters, is seen in almost every slide. Oftentimes areas occur which, both in general characters and in the more special ones, are hard to distinguish from diallage. In all the green color prevails, which has already been mentioned as characteristic of the pyroxenes in the gabbro-schists, while in the diabases of this same neighborhood the augite, where unaltered, is brown. In the matter of extinction, some areas present the normal angle of augite— 45° and more in prismatic sections¹—while others vary toward diallage. Diallage, with the typical characters, is also common. It presents some interesting illustrations of internal molecular changes, since almost everywhere in the valley the mineral is from circumference to center undergoing alteration into hornblende. A green color pervades the whole diallage individual, which some authors consider a mark of incipient alteration from diallage to hornblende, and here and there, in some cases thickly scattered through the host, are plates and fibers of

¹ Häufstabellen zur Mikroskopischen Mineralbestimmung in Gesteine, by H. Rosenbusch, Stuttgart, 1888, Tab. III, c.

dichroic hornblende. Rarely the diallage is fresh—that is, brown in color or slightly colored green; rarely, too, an area of clear hornblende appears which bears undoubted evidence of being derived entirely from a diallage individual; therefore, the great mass of material shows the intermediate condition above described, which is also illustrated in Pl. XIX, A.

Orthorhombic pyroxene appears in all stages of alteration, from the clear, fresh grains seen in specimens 5335 and 5445 (Pl. XVII, B) to the wholly altered pyroxene material lying in the long belt of knobs extending from the bend in the river, near the corner post of secs. 3 and 4, T. 115 N., R. 39 W., and secs. 33 and 34, T. 118 N., R. 39 W., westward along the north side of sec. 4, as well as northeastward through sec. 34. In the former specimens the fresh grains are strongly outlined against the plagioclastic feldspars, and exhibit scarcely any traces of decomposition, even along the cleavage lines. Other areas are partly altered (Pl. XXI, A), and still others are wholly altered (Pl. XXI, B). Thus the change can be clearly and undoubtedly traced. Much of the resultant mineral extinguishes parallel with that from which it springs, but occasionally it assumes a radial arrangement and lies in diverging fibers about the host. Hornblende is scattered everywhere through the whole series of slides examined. Many of the areas are brown and sharply marked off with cleavage lines, while others are green and ill defined. There is a strong dichroism in nearly all these individuals. In addition, many localities show a fibrous hornblende. This is always so associated with some pyroxenic mineral, usually hypersthene, as to give the strongest proof of derivation directly from it. Slide 9472 shows some areas of hypersthene fresh and almost unaltered, other areas partly altered to a fairly fibrous green hornblende, and still other areas, composed wholly of fibrous green hornblende, which bear evidence in their situation of having been formed at the expense of hypersthene individuals now totally obliterated.

Biotite, while occurring in many places in apparently independent areas, is noticed to be, as a rule, in such intimate association with the hornblende as only a descendant from that mineral can exhibit. Elsewhere it evidently springs directly from the alteration of the pyroxene. Rarely it is brown; as a rule it is green, and occasionally it is brown and green when rotated in polarized (not analyzed) light. Locally this mineral can be seen more frequently in sections from the Minnesota Falls samples than from those around Granite Falls. In some of those taken from near the road skirting the south side of the river to the north of Granite Falls no biotite whatever was seen. Much secondary hornblende is, however, present. Augite and hypersthene are both noted at these localities, and no doubt they both contributed to the formation of the hornblende.

Quartzite also occurs, but in every instance where seen it bears undoubted evidence of being a secondary mineral. The small, brightly

polarizing grains are free from inclusions. They occupy positions between the feldspars, even within them, and near the decomposing diallage areas. Also, wherever hornblende and biotite have been formed granules of quartz may be expected. The grains generally occur in clusters. Where quartz is present in isolated grains it is usually included in the other minerals.

Opaque minerals are frequent. Sometimes the areas can be proved to be pyrite, and at other times magnetite or a titaniferous magnetite must be assumed. It is common to see, microscopically, a partially or wholly altered pyroxene individual thickly strewn with spherical globules of some opaque mineral.

Apatite as an accessory is rare in all the Minnesota Falls and Granite Falls gabbro-schists; so, too, is sphene. Epidote occurs more frequently, seldom, however, in good-sized or well-formed individuals, but rather as a secondary product disseminated in small and clustered grains in the midst of other minerals, which thus play the part of host. It is thus found nestled in feldspars, in hornblendes, and in biotites.

MONTEVIDEO AREA.

Passing to Montevideo (see Pl. XI), we find a mound of the gabbro-schist on the line between secs. 18 and 19, T. 117 N., R. 40 W. The mound stands 40 or 50 feet above the flood plain of the river, but its size is not great. The foliation of the rock is clear, with a NE.-SW. strike and a dip of 30° to 50° SE. The foliation is apparently due to the alternating preponderance of the feldspathic and ferromagnesian minerals. The feldspathic portions resist weathering longer than the basic, thus forming a corrugation upon the exposed surfaces. Numerous lenticular quartz veins occur scattered over the exposure. A slightly smoky appearance is noticed, as well as the skimmed-milk opalescence which was seen so markedly developed in the gneisses at La Framboise's, below old Fort Ridgely. The opalescence here is probably due to the same cause as at La Framboise's, namely, to needles of rutile scattered through the quartz grains, since these needles are seen in large numbers. Many cavities occur in the quartz, mostly gas filled. As a rule, they are arranged in planes passing through all the constituents of the rock alike, and suggesting conditions of origin similar to those pointed out by Julien in the gneiss of New Rochelle¹. These quartz veins contain some feldspar, usually plagioclastic, and fibrous secondary hornblende. The gabbro-schist is medium to fine grained, gray in color, and somewhat weather stained. The feldspar is chiefly of the labradorite type. Some quartz is found. The proportion of basic constituents is unusually small. Some hornblende is present, as are also occasional folia of biotite. Both monoclinic and orthorhombic pyroxenes are present, showing the usual characters of these minerals as they appear elsewhere in the valley.

¹ On the fissure-inclusions in the fibrolitic gneiss of New Rochelle, by A. A. Julien: *Am. Quart. Micros. Jour.*, Vol. I, 1878, p. 103.

Northwest of Montevideo, in the SW. $\frac{1}{4}$ sec. 31, T. 118 N., R. 40 W., stands a small exposure, only 60 paces in length, rising just above the level of the prairie. The strike at this exposure is N. 30° E., and the dip is 55° SE. On the northwest side the rock is a gneiss of a reddish-gray color, considerably altered, and highly siliceous, dipping beneath the gabbro, which constitutes the larger part of the rock in sight (see fig. 6, p. 37). The gabbro is a dark-colored, highly hornblendic rock, carrying lenses of coarsely crystalline hornblende. Its feldspar is of the labradorite-anorthite type. Quartz is extremely rare, as are also magnetite and biotite. The hornblende is so strongly individualized that it can not be regarded as secondary, yet analogy and the evidence of other localities in the valley and in Wisconsin,¹ as shown by the writer, all tend toward the view that it is secondary to pyroxenes. So long ago as 1882 Irving, basing his conclusions on the combined investigation of the rocks of Wisconsin by himself and Professor Van Hise, stated the conviction "that all of the hornblende of the rocks of this region is but altered augite."² Those words are of significance here, since the rocks of the two States are very similar in general characters, and at the time the report cited was published the schistose gabbros were for the most part classed as gneisses.

The pyroxene is in part monoclinic, doubtless three-fourths diallage. Its color is green, and there are evidences of alteration from the incipient stage to that where individuals are completely changed to other mineral species. The orthorhombic pyroxene, hypersthene, is like the same mineral in the many localities to the southeast, already described.

ODESSA AREA.

The last point up the river which discloses the presence of gabbro-schists is a moderate-sized exposure south of the Odessa station, on the Chicago, Milwaukee and St. Paul Railway, 1,200 paces N. and 1,500 paces W. of the southeast corner of sec. 9, T. 120 N., R. 45 W (sp. 5334, 5335). A knob some 20 feet in height and not more than 250 paces in length, largely turfed over, stands in the bottoms. The strike is N. 45° E. and the dip is 45° NW., although in places the schists seem to dip toward the southeast. The rock is dark colored, considerably weather stained at the surface, and very badly shattered. The texture is fine, for this type of rock, and the lamination is quite distinct. Both color and texture, aside from this character, are very even. Owing to the shattered condition of the rock, the effects of weathering extend rather deep. A rusted condition is seen along the sides of the fractures, penetrating the rock an inch or more. Where the fracturing is fine this condition induces a concentric weathering, which is conspicuous on the loose boulders lying about on the outskirts of the quarry.

¹ Notes of a geological excursion into central Wisconsin, by C. W. Hall: Bull. Minn. Acad. Nat. Sci., Vol. III, No. 2, 1891, pp. 256, 257.

² Crystalline rocks of the Wisconsin Valley, by R. D. Irving: Geol. Wisconsin, Vol. IV, 1882, p. 714.

Quarrying has disclosed the rock to a depth of several feet. From this depth the freshest specimens show an unusually fresh and unaltered condition of the rock. It is a typical hypersthene-gabbro-schist or norite-schist (sp. 5335, sl. 2263). (See Pl. XVII, B.)

It was from this quarry that a sample of an augite-schist was secured for the Educational Series of Rock Specimens of the United States Geological Survey (No. 140). The following is summarized from a description by W. S. Bayley: ¹

The rock is a very dark gray crystalline mass, with an obscure schistose structure and a sugary texture. Its grain is so fine that but one of its constituents—biotite—may be recognized with any degree of certainty. This is uniformly scattered through the rock. In addition to this, there can also be detected a granular white mineral whose particles are so small that their nature can not be determined. The specific gravity of the rock is 2.770.

In thin section the rock is seen to consist chiefly of quartz, plagioclase, and pyroxene, with biotite, garnet, pyrite, and magnetite as accessory constituents. In natural light there appears an apparently homogeneous, colorless groundmass, in which lie large, irregular grains of a very highly refractive mineral with well-marked cleavage, smaller dark-brown flakes, small irregular or rounded grains or aggregates of grains of an opaque substance, and occasional isolated, highly refractive grains of a pinkish tinge. When examined with low power a certain parallelism may be detected in the arrangement of the various minerals. The majority of the brown flakes and of the highly refractive grains lie with their long axes in approximately the same direction. This supports the evidence of the unaided eye that the rock is schistose, and also the conclusion that the schistosity is not well marked.

When examined under crossed nicols the apparently homogeneous groundmass is seen to be an aggregate composed of very irregularly shaped interlocking grains of quartz and feldspar. Both are perfectly pellucid in natural light, and both contain the same kinds of inclusions. They may be distinguished by the brighter polarization colors of the quartz and by the twinning striations of the feldspar. From the intricate manner in which they interlock, it is impossible to determine which is the older. Both include small particles of all the other components, and therefore they must be younger than these. They contain also tiny liquid inclusions—a few with movable bubbles—large quantities of black, red, and green dust, and irregularly outlined green and reddish inclosures that appear to be either decomposition products of some substance whose nature can no longer be determined, or secondary infiltration products. The latter supposition seems the more plausible, on account of the varied character of the inclusions, which are at the same time undoubtedly such as are produced by secondary infiltration.

The feldspar, like the quartz, is in irregular grains, colorless, and

¹ See Bull. U. S. Geol. Survey No. 150, 1898, pp. 358-362.

pellucid. It is a plagioclase. The twinning striæ usually occur in a single series of parallel lines, but sometimes they appear in two series, crossing each other at nearly right angles. The maximum symmetrical extinction of two contiguous lamellæ, measured against their line of contact, is about 26° , indicating a plagioclase somewhere in the labradorite series. The specific gravity of the feldspar separated from the rock powder was 2.673. In any given position of the section between the nicols, one portion only of the lamellæ of any series of most grains is dark, the other ends of the lamellæ remaining bright. As the section is revolved the darker portions become bright, the dark zone gradually moving toward what were the bright ends in the first position of the section, thus showing fine undulatory extinction.

The irregular, highly refractive grains have a slight pleochroism in pale-greenish and pinkish tints, the latter when the most prominent cleavage runs perpendicular to the vibration plane of the lower nicol. The extinction is parallel to this cleavage where only one set of cleavage lines is observed, and on sections where two cleavages are seen it bisects the angle between them. The axis of elasticity parallel to the single cleavage is smaller than the one at right angles to it, and the double refraction is low. Since the long axes of nearly all the grains run about parallel to the plane of schistosity of the rock, and the sections are made parallel to this plane, it is not surprising that so few basal sections of the mineral can be found. In the one or two that may be discovered in each section there are two series of cleavage lines, which make with each other angles of about 88° and 92° . No inclined extinctions were seen in any section where only one set of cleavage lines appeared. The mineral is probably an orthorhombic pyroxene. It is usually fresh and free from inclusions. In sections cut from the weathered portions of the rock, however, an interesting alteration is observed to be in progress. The cleavage lines of the pyroxene are filled with a brown pleochroic substance without definite morphological characters. This brown substance gradually spreads into the surrounding pyroxenic material, replacing it in part, so that often what at one end is a perfectly fresh, almost colorless pyroxene is at the other end a mass of brown, pleochroic substance. As the amount of the brown substance increases its character becomes more pronounced, until finally the substance takes the form of biotite. The biotite often lies embedded in pyroxenic material, often it borders large grains of that material, and sometimes it occurs in the spaces between neighboring grains. There can be no doubt that it is an alteration product of the pyroxene.

The greater portion of the biotite in the section is in isolated grains between the colorless constituents quartz and plagioclase. Its long axes are nearly always approximately parallel to the long axes of the pyroxene. The mineral shows the ordinary pleochroism of mica. It is, of course, impossible to state positively that all of the biotite in the

rock has the same origin as that found in and near the pyroxene, but since it has exactly the same properties of the secondary mica we may say that it is probably of the same origin.¹

The only constituents remaining to be described are garnet, pyrite, and magnetite. The first mentioned is in almost colorless, very highly refractive grains, without cleavages and without inclusions. They are irregular in cross section, but in outline approximate more or less closely to circles. They may be easily distinguished from all the other constituents, since they are perfectly isotropic between crossed nicols. The large grains are crossed by irregular fracture lines, distinguishable from cleavage cracks by their lack of parallelism. The garnets are found usually as inclusions in quartz. Reasons are given later (p. 102) for believing that the more abundant garnets of a gabbro-schist are of secondary origin. If this conclusion is true, it is highly probable that the garnet of this rock is also secondary, although the evidence is not so clear as in the case of the gabbro-schist referred to. The pyrite and magnetite both occur in irregular opaque grains that may be distinguished from one another by the brassy luster of the former in reflected light.

In an attempt to name the rock, we are met with the difficulty always experienced in discussing the classification of schistose rocks. No satisfactory method of classifying them has yet been proposed. It would seem best to confine the "schists" to aggregates of quartz and some bisilicate, and the "gneisses" to aggregates of quartz, orthoclase, and some bisilicate. According to these distinctions, our rock is neither a schist nor a gneiss, since it consists essentially of quartz, plagioclase, and pyroxene. It is a schistose rock with the composition of gabbro. Roth designates such rocks as zobtenites, and Dathe calls them flaser-gabbros. The flaser-gabbros, however, have a larger amount of hornblende; consequently our rock is excluded from that class. If we accept zobtenite as a general name covering all rocks produced from gabbros by pressure, it may safely be applied to the rock under discussion, for its composition is the same as that of the gabbros, and it has evidently been subjected to great pressure. Professor Hall, who has made a careful study of this rock in the field, thinks there can be no doubt that it was once a typical gabbro. If, however, we disregard the plagioclase as a classificatory element, we may call the rock a biotite-augite-schist.

In either case it is extremely interesting. Augite-schists are very rare, having been described only a few times in the literature of American petrography.² Zobtenite without hornblende, in which the pyroxene

¹Preliminary description of the peridotites, gabbros, diabases, and andesytes of Minnesota, by M. E. Wadsworth: Bull. Geol. Nat. Hist. Survey Minnesota, No. 2, 1887, p. 65.

²Microscopical observations of the iron-bearing (Huronian) rocks from the region south of Lake Superior, by Arthur Wichmann: Geol. Wisconsin, Vol. III, 1880, p. 645. Rocks of the Wisconsin Valley in the vicinity of Wausau, by R. D. Irving: *ibid.*, Vol. IV, pp. 660 and 694-6. Preliminary paper on an investigation of the Archean formations of the Northwestern States, by R. D. Irving: Fifth Ann. Rept. U. S. Geol. Survey, 1885, p. 211.

and the plagioclase are perfectly fresh, are even more exceptional in occurrence than augite-schists, for the pressure that so squeezes a massive rock as to flatten its constituent grains produces a condition very favorable to the alteration of pyroxene into hornblende. Schistose gabbros, in which hornblende exists in large quantities, have been described in many foreign publications and in several in this country. It is not necessary to enumerate them here.¹

HYPERSTHENE-FREE GABBRO-SCHISTS.

In several localities in the valley the gabbro-schists show no traces of hypersthene. In all other respects they are identical with the hypersthene-bearing masses just considered. Indeed, in several instances a series of samples was taken, one of which would exhibit well the characteristic hypersthene, while another, from the same belt and only a few feet away, would prove to be an ordinary nonhypersthene-bearing gabbro. At no place was there noted any geological change in general direction and situation, and the most careful examination failed to show any break whatever in the arrangement of the rock series. Further, the examination of samples in the study served to show no differences whatever between the several rocks, save the presence of hypersthene in one and the absence of it in another; every scale of proportion between these two extremes was seen.

At 800 paces N. and 400 paces W., sec. 34, T. 112 N., R. 33 W., there stands an exposure of a somewhat altered gabbro. It is a narrow belt, not more than 175 or 200 paces long, elevated only a few feet above the level of the flood plain of the river. Some contortion can be seen in the laminae, but the general direction is NW.-SE. The laminae stands about vertical. The rock is dark green in color, and under the hammer is extremely tough. Lighter-colored bands alternate with the darker and more basic. Pyrite is frequently seen in compact nests of crystals. A fine texture generally prevails.

Quartz has entered to no little extent into the mineral composition of this rock. It has assumed the pegmatoid character, and in many places affords a matrix to the other and older constituents, particularly to the kaolinized feldspars. Only occasionally is the feldspar sufficiently preserved to disclose its labradoritic character. The pyroxenic contents are augite and diallage in about equal proportions. The normal extinction of these two minerals is readily shown.

While it is more or less true of both pyroxenes, it is particularly so of the diallage, that it is in large areas and that the feldspars and other minerals occupy vermicular channels and spherical spaces within the diallage matrix. Pl. XXIII, *B* (from sp. 5199), shows a field of this kind in which feldspar, quartz, and hornblende lie in canals and open-

¹ The greenstone-schist areas of the Menominee and Marquette regions of Michigan, by G. H. Williams; Bull. U. S. Geol. Survey No. 62, 1890, pp. 52, 216.

ings in a single area of diallage. The boundary between the diallage and the included minerals is partly sharp and clear and partly broken up into narrow reaction rims, along which there seem to lie several minerals.

In the freshest specimens the augite and diallage are almost unaltered. In others they are both altered to hornblende. In places whole areas of these minerals are altered, and in other places rims of hornblende surround cores of the pyroxene. A decidedly fibrous character is in some places assumed by the secondary hornblende, and in other places numberless plates of green hornblende of minute size thickly stud the areas of pyroxene and give a green color to entire individuals. In the more weathered portions of the rock probably more than one-half of the bulk of the basic constituents is secondary hornblende, and there is in addition a considerable sprinkling of biotite. Between the folia of biotite are wedged many lenses of quartz and epidote. (See Pl. XX, C.)

Around Granite Falls several localities show no appreciable quantity of hypersthene in the gabbro-schists. South of Granite Falls, in sec. 4, T. 115 N., R. 39 W., lie some exposures of these rocks. While the great mass of the gabbro which stretches from this section northward, extending, with occasional interruptions, 2 or 3 miles, is hypersthene-bearing, several localities may be cited where no hypersthene whatever was seen.

In sec. 4, at 1,500 paces north of the southeast corner, some excavating has been done in a search for gold. The veinlike matter which has already been mentioned as occurring here was followed about 20 feet down. In the neighborhood of the vein the rock is decidedly massive, but at the distance of a few feet from the contact it has a distinctly schistose character. The pieces secured show admirably the shattering of the feldspars and the anastomosing through them of the veins of hornblendic material. A strongly marked diallage is the other leading constituent. No hypersthene was seen.

The rock at this locality shows some features of so much lithologic interest, particularly in the presence of a generous proportion of garnet (see Pl. XXII, B), that a set was collected for the United States Geological Survey's Educational Series of Rock Specimens (No. 109). Prof. W. S. Bayley prepared the description for this series, and from his description¹ the following summary is taken:

The prevailing color of the rock is dark green, speckled with large patches of dark red, and small areas of greenish yellow or white. Upon close inspection the yellow and white areas are seen to be the glistening cleavage surface of a striated plagioclase. The red areas are the surfaces of a dark-red, very hard, transparent mineral. It has no distinct cleavage, and is insoluble in acids. The properties are those of garnet. The nature of the dark-green matrix in which the

¹ See Bull. U. S. Geol. Survey No. 150, 1898, pp. 282-286, digitized by Google

garnet and plagioclase are embedded can not be determined, though from its dark color it may be assumed to be very basic. The specific gravity of the rock is 3.105.

Under the microscope the thin section shows a granular aggregate of plagioclase, green augite, garnet, and magnetite, with small quantities of green hornblende, a few grains of quartz, and tiny crystals of apatite.

The plagioclase is in irregular allotriomorphic grains, crossed by well-defined cleavage cracks and irregular fissures filled with decomposed products and stained by iron oxides. The feldspar is clear and colorless, except where rendered cloudy by inclusions. The most abundant of these are tiny flakes of chlorite and irregular masses of an opaque earthy substance, besides dustlike particles of magnetite and little nests of a brightly polarizing calcite. All these are usually abundant in the neighborhood of the fissures but are rare in the other parts of the grains. Other plentiful inclusions are long, narrow, apatite crystals with the ordinary characters. The average length of these apatite crystals is about 0.1 mm., and their thickness some 0.05 mm., though a few have cross sections measuring 0.2 mm. in diameter. Augite, hornblende, and large masses of magnetite are also included in the plagioclase, but these will be spoken of later.

Under crossed nicols the plagioclase twinning becomes very apparent as mediumly wide bands, usually running entirely across the grains. Some curve slightly, others wedge out as they pass toward the interiors of the grains, and still others spring from the sides of cracks, etc. These phenomena indicate that the rock has been subjected to pressure since it solidified. The schistosity observed in the field is probably a result of this. In certain restricted areas in the section, notably in the neighborhood of large garnets, there is often a second series of twinning lamellæ, with more or less undulous extinction, cutting the first series at some acute angle. The second series comprises numerous lamellæ, not so distinct as those of the first set and not so sharply marked off from one another. The specific gravity of the plagioclase is somewhere about 2.68, or near the andesine division in the plagioclase series, though probably a more basic member is also present, with a density of about 2.72.

The next most abundant component of the rock is a pyroxene, in green allotriomorphic grains and older than the plagioclase. This augite, where fresh, is marked by two series of cleavage lines, crossing each other at angles of about 90° in basal sections, and in other sections by a single series of parallel lines. The extinction is usually inclined to these. The augite in these sections may easily be distinguished from hornblende by the lack of strong pleochroism and by the large angles of extinction against the cleavage lines in a single direction, which often reach as high as 43° , whereas those of hornblende rarely approach 24° . Occasionally a slight difference in absorption may be detected in the mineral, but this is so slight that it may easily be overlooked.

In addition to the two cleavages mentioned as prominent in basal sections there is often another, presenting itself as a series of closely crowded parallel lines, bisecting the larger of the two nearly rectangular intersections of the cleavage lines. Since the shorter of the two lateral axes in pyroxene is the orthoaxis, this cleavage must be parallel either to the orthozone or to the orthopinacoid. It is determined to be an orthopinacoidal cleavage, which is characteristic of diallage. At one time this cleavage of diallage was regarded as original, and the mineral was considered as a distinct species of pyroxene. Now, as shown by Professor Judd,¹ it is known that the cleavage is secondary, and that its origin is often the direct consequence of pressure to which the rock containing it was subjected.²

Though much of the diallage is fresh, a still larger proportion is altered. The interior is often stained brown, or yellowish brown, and lacks the power of polarizing brilliantly. A little magnetite, in rounded grains, has formed around the edges of the altered portion, and a more or less fibrous cleavage has developed in it. In places the yellowish substance occurs in little plates or needles, arranged in parallel lines inclined to the cleavage, thus giving rise to the appearance of fine cleavage. In some cases the lines are so straight and narrow that they are with great difficulty distinguishable from true cleavage even under a high power. The origin of somewhat similar inclusions, so common a feature in diallage and hypersthene, has been the subject of much discussion, Judd considering them secondary infiltration products along planes of easy solution,³ and others regarding them as original inclusions taken up by the mineral during its growth.⁴

Around the outside edges of the pyroxene another alteration is observed, it being surrounded by large plates or small granules of a bright-green substance with strong pleochroism in yellowish-brown and dark bluish-green tints and an extinction inclined to the cleavage. This substance, which is a hornblende, surrounds the pyroxene as a narrow rim, which sometimes extends into the pyroxene grain and at other times is formed of granules that seem to have been added to the grain after its formation. In either case the substance is to be regarded as secondary in origin.⁵ In a few cases, where the pyroxene grains were small, the entire substance has changed, and in its place are now areas of hornblende that might be regarded as original were it not for the fact that so much of the hornblende of the rock is undoubtedly secondary. Another product, in some places formed by the alteration of pyroxene, is biotite. This is in small, reddish-brown flakes mingled with hornblende on the periphery of the areas.

¹ On the Tertiary and other peridotites of Scotland, by Prof. J. W. Judd: *Quart. Jour. Geol. Soc. London*, 1885, pp. 378-379.

² Preliminary description of the peridotites, gabbros, diabases, and andesytes of Minnesota, by M. E. Wadsworth: *Geol. Nat. Hist. Survey Minnesota, Bull. No. 2*, 1887, p. 55 et seq.

³ *Loc. cit.*, p. 354.

⁴ Discussions of the peridotites and norites of the Cortlandt series, by G. H. Williams: *Am. Jour. Sci.*, 3d series, Vol. XXXI, Jan., 1896, p. 33, and Vol. XXXIII, Feb., 1897, p. 143.

⁵ Note on the enlargement of hornblendes and augites in fragmental and eruptive rocks, by C. R. Van Hise: *Am. Jour. Sci.*, 3d series, Vol. XXXIII, May, 1897, p. 386.

The magnetite and pyrite appear as large irregular grains scattered more frequently near the pyroxene and garnet than elsewhere in the rock. Both have resisted alteration and both are equally opaque.

The garnet is the characteristic mineral of the rock. It is in large, cellular masses, sometimes measuring a half inch in diameter. In the section it appears as a highly refractive, isotropic, deep-pink substance filled with inclusions and crossed by many irregular cracks, along the sides of which are stains of yellow iron oxides. So large and so numerous are the inclusions that the garnet substance, in its arrangement, reminds one of the section of a coarse sponge saturated with various colorless products. The largest and most striking of the inclusions are quartz grains. These are colorless and without cleavage traces. They inclose little mica plates, apatite crystals, dust particles, and thousands of small liquid-filled pores arranged in lines. Under crossed nicols most of the larger grains break up into aggregates, with the lines of inclusions passing from one grain into another without interruption. Occasionally some of the clear inclusions in the garnet are discovered to be plagioclase, but these are comparatively rare. The other substances inclosed by the garnet are small pieces of biotite, crystals and particles of magnetite, crystals of apatite, and thousands of tiny cavities filled with liquid. As in the quartz, these are arranged in lines, and the lines are sometimes continuous in both substances. This latter phenomenon would indicate that the inclusions are of secondary origin, and that they were formed after the quartz and garnet had assumed their present positions.

The associations of the garnet show it to be younger than the other constituents. Its cellular nature is evidence that it did not separate from the magma whose cooling gave rise to the main portion of the rock, because garnet formed in this way is usually among the oldest products, whereas in the present case the mineral is younger than even most of the quartz.

Another form in which the garnet exists is in small granules surrounding the magnetite. Here the mineral has the same properties as when in large pieces, except that it contains no large inclusions of quartz and feldspar.

The quartz is in colorless masses surrounded by garnet, as already mentioned, and also in larger pieces associated with the garnet but not included in it. It usually occurs most abundantly near the garnet, in the sections containing a great deal of that mineral, and is almost if not totally absent from the sections in which there is none.

Since the garnet is probably secondary, i. e., since it was probably formed after the main portion of the rock had solidified, it is probable that the quartz also is of secondary origin, and that the original components of the rock were essentially diallage and plagioclase, with magnetite, pyrite, and apatite as accessory constituents.

The rock is a gabbro. The principal mass under study is schistose, but it is evident that this is an imposed structure, since even in the

apparently massive variety represented by the hand specimen abundant indications of pressure are present. The massive phase, since it is characterized by the garnet, must be denominated garnetiferous gabbro. The schistose variety, being a squeezed gabbro, may be called a gabbro-schist.

Another rock, on the Russell farm, south of Minnesota Falls, possesses so much lithological interest that a set of specimens was selected to constitute one number of the Educational Series collected and distributed by the Survey (No. 144). The exact location is 800 paces N., 100 paces W., sec. 11, T. 155 N., R. 39 W. In the field, at this particular spot, the rock is distinctly foliated; it strikes nearly E.-W. and dips N. at 30°. The hand specimen at first shows little evidence of schistosity, but closer examination discloses the long axis of a majority of the grains lying approximately in the same direction, although not necessarily in the same plane. The following summary also is from the description prepared by W. S. Bayley.¹

The rock is a medium-grained, distinctly crystalline aggregate of a white, striated plagioclase and a lustrous black hornblende showing a good cleavage. The cleavage surface is less even than that of mica.

The thin section of the rock reveals a general parallelism in the arrangement of its darker constituents. Most areas show only a coarse-grained aggregate of plagioclase and light-green hornblende. Other areas show in addition a very light-colored, highly refractive augite.

The plagioclase is in very irregular grains, clear and colorless except for tiny dustlike inclusions scattered through them. In addition to these it contains also tiny specks of magnetite and small flakes of green hornblende. Under crossed nicols the twinning lamellæ, in the majority of cases, form a single series of parallel lines. In other cases the lamellæ form two series, cutting each other at angles of about 78°. Some of the lamellæ run entirely across the grains, others spring from their edges and wedge out toward their centers, while still others spring from the sides of cleavage cracks and extend only a short distance into the feldspathic substance. In many grains the lamellæ have an undulatory extinction, different portions of the same lamella extinguishing in different positions of the stage as it is revolved. All these phenomena indicate that the feldspars have been subjected to pressure, which is probably the same as that producing foliation in the rock mass. The maximum symmetrical extinction of contiguous lamellæ is somewhere in the neighborhood of 33°, and the density of the mineral is 2.731. It is thus a basic bytownite.

Though the main mass of the feldspar is fresh, as has been said, the corners of grains and the small areas between neighboring ones are often filled with a micaceous, brightly polarizing substance, in tiny flakes, accumulating in little cloudy masses in and between the fresh plagioclase grains. The substance has the peculiarities of kaolin, a

¹ See Bull. U. S. Geol. Survey No. 150, 1898, pp. 369-372.

common alteration product of all feldspars, and is undoubtedly that material.

The hornblende is in large masses, of green color and of moderate pleochroism. Many of the grains have but one set of cleavage lines. The extinction against these lines varies between parallelism and an inclination of 28° , according as the section is parallel to the orthopinacoid or to the clinopinacoid, and the pleochroism is in clear-green and yellowish-green tints. Other grains have two series of cleavage lines. Where the lines are most distinct and most sharply cut, the angles made by the two series are 124° and 56° . The pleochroism is dark green and light greenish yellow; α =greenish yellow, β and γ =green. Absorption, $\beta=\gamma>\alpha$. The different individuals of the mineral are very irregular in shape, and usually four or five aggregate into groups. Most of these are simple individuals, but others have two or more parts in twinned relation to each other. The only inclusions noted in the hornblende were little grains of magnetite, small dust particles, and, in certain sections, masses of a light-colored, highly refractive mineral—augite.

This augite is found only in the interior of masses of green hornblende. It has a very high index of refraction, and is not pleochroic. It is either colorless or a very light shade of green. Under favorable conditions it may be seen to be crossed by two series of cleavage cracks making angles of nearly 90° with each other. The extinction bisects these angles, and the polarization colors are very brilliant. This augite is not always sharply separated from the surrounding hornblende. It gradually assumes a greenish tinge on its edges. This color deepens as the distance from the interior of the augite increases, and the substance acquires more or less pleochroism, until it finally becomes indistinguishable from the surrounding hornblende. This relation of the two minerals indicates that the hornblende has been derived from the augite.

Occasionally, in the edges of hornblende grains, and especially where these are in contact with feldspar, small, reddish-brown flakes of strongly pleochroic biotite may be found. These flakes sometimes extend, with frayed ends, far into the hornblende. Biotite is present in but small quantities, either between plagioclase and hornblende, as described, or between neighboring hornblende grains. It is probably secondary, being due to a reaction between the hornblende and the plagioclasic materials. The alteration of hornblende into biotite is by no means unknown.¹

The chief components of the rock as it at present exists are plagioclase and hornblende. The latter is evidently an alteration product of augite, and the plagioclase is bytownite. Both minerals are allotropic, but the rock has been given a schistose structure by pressure.

¹ The greenstone-schist areas of the Menominee and Marquette regions of Michigan, by G. H. Williams: Bull. U. S. Geol. Survey No. 62, 1890, p. 182.

If we reconstruct the predecessor of the schist, we shall have a granular aggregate of plagioclase and augite—i. e., a gabbro. From the presence of hypersthene in the fresher rocks in the immediate neighborhood of this specimen, it is fair to presume that it was originally a hypersthene gabbro. Its composition is now that of diorite, and its structure is schistose. Hence the rock may be termed a gabbro-diorite.¹

Near Russell's farm, sec. 12, T. 115 N., R. 39 W., a sample was taken which lay almost alongside the gabbro just described—a typical representative of an altered gabbro. In this sample (sp. 5279) the pyroxene is almost completely altered to hornblende, yet enough remains to show the monoclinic habit of the constituent. The hornblende in this specimen exhibits in a very beautiful manner the characteristic granular condition which the secondary phase of this mineral assumes in nearly all localities and among all rock types of the Minnesota River Valley and of central Minnesota. Quartz is here an abundant accessory; so, too, is biotite in those areas within and around the space formerly occupied by the pyroxenes (Pl. XXII, A).

In the SW. $\frac{1}{4}$ of the SW. $\frac{1}{4}$ sec. 2, T. 113 N., R. 36 W., there stands a long, low belt of rather coarse hornblendic schist (sp. 5260, 5739, 5740, 5741). Everywhere over the surface course light-colored granitic veins. While these veins run in every conceivable direction, a general parallelism with the laminae of the schist can be clearly traced. Their field relations to the ordinary gneisses can not be made out, further than that they lie near them, direct contact being thoroughly concealed.

The feldspars are well preserved in their general characters, few areas showing a breaking up into kaolin and here and there a staining by ferric oxide. Only a very few individuals of pyroxene are left from the alteration into dark-green hornblende, and these are green in color and augitic in optical characters. A few accessory minerals were also noted in the thin sections. So far as studied there seems to be little difference, in the degree of preservation shown by the individual minerals, between the finer, compact rock and the coarser, crumbling phases.

Save in the presence of augite at this locality there is almost no difference perceptible between this schist and that in sec. 4, T. 114 N., R. 37 W. (sp. 5376).

Three miles up the river from La Framboise's, in sec. 34, T. 112 N., R. 33 W., there stands a series of small knobs of a schistose rock, extremely tough under the hammer and almost unweathered. On macroscopic inspection there appears a contortion so marked that the true direction of the schistosity can not be accurately stated, but an average of measurements shows it to be nearly NW.-SE. The exposures stand about vertical. The contorted bands exhibit frequent nests of pyrite and many lenticular feldspathic streaks. The color of the rock is dark green, the texture fine.

¹ The gabbros and associated hornblende rocks occurring in the neighborhood of Baltimore, Md., by G. H. Williams: Bull. U. S. Geol. Survey No. 28, 1886, pp. 17, 27-32.

The three principal minerals present are a plagioclasic feldspar, augite, and magnetite. The feldspars are badly decomposed. Their alteration has proceeded so far that only occasional individuals are still sufficiently fresh to show the twin lamellæ. The two replacing minerals of the feldspathic constituent are kaolin and quartz, the last-named mineral appearing in very numerous but scattered granules.

While the feldspars are thus largely obliterated, the augite areas are unusually fresh. A green color predominates, and cleavage markings can be seen almost everywhere. The extinction angle is around 55° , thus indicating a normal augite. Not infrequently the individuals are of so large size that they include many other minerals, as feldspars and quartz. Some twinned forms occur. The hornblende, which for the most part seems to be secondary to the augite, is in small areas, either as narrow borders around the areas of augite or as small detached areas within the grains. In places biotite is present, and a characteristic of this mineral seems to be the intercalation of lenticular segregations of epidote and quartz between the folia. Either this is due to the alteration of some mineral which in its change produces both biotite and epidote, or the biotite has since its maturity yielded, as an alteration product, the material which has developed into the interfoliar epidote.

PYROXENE-FREE GABBRO-SCHISTS OR GABBRO-DIORITES.

In their alteration the gabbro-schists in several localities show a total disappearance of the pyroxenic constituent so characteristic of the fresher members of the series and its replacement by hornblende or by hornblende and biotite. In all their field relations—and they have been studied from one end of the valley to the other—no conditions of any sort were detected which might be regarded as peculiar to one member of the series and not to be found in another. The more or less schistose structure could be seen almost everywhere. The localities where this structure is lacking have already been indicated. The dark color, modified by the proportion of feldspar or the degree of hornblendization, was repeatedly seen. A medium texture always prevailed, frequently modified, however, by the occurrence of coarser segregations or laminae.

While veins or dikes of a granitic character are abundant throughout the gneissic series, they are generally rare in the gabbro-schist.

In the west half of sec. 21, T. 114 N., R. 37 W. (Pl. VIII), there stands a mass of highly contorted hornblende-schist which is dioritic in type (sp. 5376). Some bands are biotitic. It is surrounded by several other knobs, at no great distance, which are gneissic. No well-defined direction of schistosity can be stated, yet the general strike is E.-W., with a northward dip.

Well-individualized hornblende occupies about two-thirds of the bulk of the rock. Frequently twinned individuals occur. The feldspar is

of the labradorite-anorthite type, and, while very fresh and strongly twinned, shows great unevenness in composition. In places a cloudiness, due to decomposition, completely hides the feldspathic characters, and in other places a ferric oxide is disseminated to a very considerable extent through the feldspars and hornblendes alike. Some rather large crystals of apatite were seen. This exposure seemed to be quite isolated from that of any other rock of similar type. Those which most resemble it are the dark-colored schists in sec. 2, T. 113 N., R. 36 W. (Pl. VIII), and in sec. 31, T. 118 N., R. 40 W. (Pl. XI), both of which have already been noted, the former still carrying some portion of pyroxene and the latter containing hypersthene.

Among the high, bold knobs of gneissic rocks which stand scattered throughout secs. 3, 4, 5, 10, and 11, T. 113 N., R. 36 W. (Pl. VI), are several interlaminated belts of hornblende-schist. In addition to these alternating bands, there are many lenticular nests, large and small. The texture is medium; as a rule, the broader, thicker bands are the coarser. The schistosity lies in a very regular direction, striking E. 10° S., and dipping southward from a low angle to one as high in places as 75° . In mineral composition this rock varies little from that just mentioned. The feldspars are more altered here than is the usual condition.

Coming again to Granite Falls and Minnesota Falls (Pl. X), several localities may be noted where the diorite-schists occur. In the south part of the village of Minnesota Falls, at 1,775 paces N. and 75 paces W., in sec. 11, T. 115 N., R. 39 W., is a finely crystalline schist (sp. 5418) which is badly shattered. It lies in the vicinity of a granitic vein of considerable size and only a short distance from a very prominent dike (sp. 5419). Examination indicates that this rock was originally a gabbro-schist, in which, at the present time, the pyroxenic constituents are completely obliterated. In spite of this fact the rock is fresh, and the existing mineral constituents can be diagnosed with ease. (See Pl. XXI, B.)

Starting southwestward from the corner post between secs. 33 and 34, T. 116 N., R. 39 W., and secs. 3 and 4, T. 115 N., R. 39 W., crossing the Minnesota River and proceeding a few degrees south of west for a mile or more through sec. 4, one passes a succession of knobs which have a schistosity striking westerly and dipping southerly. The prevailing color is dark, due to the predominance of hornblende. The texture is medium, and the whole aspect of the rock is bright and fresh. The mounds are not high; their linear arrangement and shape are due to the strike and inclination of the rock belt. There is little veining to be seen, and both structure and texture are very uniform throughout.

Still another locality is in the heart of Granite Falls, just north of the court-house and the several churches of the city. A belt of rather coarse gabbro-gneiss extends down from the northwest, swings round

to the right, is interrupted by a narrow dike, and disappears toward the southwest. While the rock here is as fresh as along the belt just mentioned, it has a lighter color and a more gneissoid aspect, due to a smaller amount of hornblende. The term "gneissoid" is applied to indicate that the proportion of feldspar at this locality is much larger than in the typical exposures. Everywhere the feldspar individuals are fresh, brightly polarizing, and affected by alteration to a comparatively slight extent. Twinning is everywhere very pronounced, and the extinction angles point to the labradorite-anorthite type. The granular structure is very uniform, and all the feldspars are apparently of a single generation. Wherever alteration has crept in, it results in segregations of finely crystalline granules in the central portions of the individuals affected. Very little quartz was noticed, and that appeared to be secondary.

The leading basic constituent in all the specimens examined is hornblende. As a rule it is the green variety, but in one or two instances brown hornblende is present as the center or core around which the green is arranged. In a few instances a highly fibrous condition is seen, with a rim of deep green surrounding the areas packed with fibers. Since in this same group of rocks (sp. 5285, 5238, and especially 5445) the mineral hypersthene is seen changing into this fibrous hornblende, we can assume that origin for this portion of the hornblende. There is certainly every indication in the external and internal characters of these rocks to warrant such conclusion. If this view of the origin of the rocks carrying the fibrous hornblende be tenable, it must also be so of those in which this mineral is expanded into folia and grains, whether the folia and grains be green or brown in color. The same reasoning can be extended also to include masses in which a portion of the alteration product is chlorite and those in which a part of the hornblende has been further changed into biotite.

If lithologic proof of the character cited be insufficient to show the relationship of the hypersthene-bearing, the hypersthene-free, and the pyroxene-free rocks of this locality, the field relations may be cited. The belts of hypersthene-bearing rocks which occur in fine exposures in sec. 34, T. 116 N., R. 39 W. (Pl. X, sp. 5445, 5293), can be followed step by step across the river in a direction a little south of west, through sec. 4, T. 115 N., R. 39 W., until all the rocks of the valley finally disappear under the glacial drift which rises as the southwestern boundary of the river plain.

In the exposures north of the court-house, where the hornblende is scarce, the feldspars are apparently identical with those to the south in the long belt stretching from the neighborhood of the railway station entirely across the valley. But between the feldspar individuals there are bands and clusters of finely granular quartz. These lie, as a rule, along the sides of the feldspars which show most evidence of corrosion, and they bear every aspect of secondary origin. The hornblende

areas are usually clusters of individuals of small size lying compactly together, nearly all of them having substantially the same crystallographic orientation. They are undoubtedly secondary. The minerals adjacent to a dike are in no way different from the individuals of the same species lying many feet away. The rock is undoubtedly secondary to some phase of preexisting gabbro. It may have become somewhat more silicified than the other diorites and many of the gabbro-schists of the valley during the metamorphism of the rocks.

On the top of the hill in the western part of the city of Granite Falls is a rock (sp. 5441) of rather peculiar mineral and textural composition. In only one other locality in the whole valley has such a rock been found, namely, at Montevideo. It is a somewhat porphyritic diorite. No augite is present, hornblende abounds, and biotite is plentiful. The hornblende is green and somewhat granular, with occasionally well-formed crystals extending into the old and partly kaolinized feldspars. The porphyritic feldspars are plagioclases, with the twinning striæ largely obliterated through the kaolinization. Around them is fresh, transparent feldspathic material, apparently orthoclase. The apatite needles, which are thickly strewn in every section, are of varying sizes and rarely entire. Many of them are not only broken and displaced, but are shoved until they overlap one another. (Pl. XXIV, B.) Aside from these minor characters the rock shows little effect of pressure.

CHAPTER VI.

PERIDOTITE AND SERPENTINE.

PERIDOTITE.

Peridotite occurs in only one definitely located spot in the Minnesota River Valley so far as is at present known. That spot is 1,300 paces N., 600 paces W., sec. 9, T. 112 N., R. 34 W., being 3 miles in a direct line southeast of Morton. As was stated in Chapter III, bowlders are found within a few miles of this place, in secs. 32 and 33, T. 112 N., R. 33 W., which are of essentially the same material.

The exposure in sec. 9 shows only a small area. The rock stands beside one of the many small lakes formed through the abandonment of a former channel by the river. Its entire length measures 300 paces, and a portion of this is now covered. There are no other outcrops of the crystalline rocks within a half mile, and in this exposure itself there is no visible evidence of other rock species than peridotite and its alteration product, an impure serpentine; therefore its relations to the nearest neighboring rocks, the chlorite-gneiss of sec. 10 and the ordinary hornblendic biotite-gneiss in the south half of sec. 4, could in no way be determined.

The present shape of these peridotite knobs is undoubtedly due to the erosion of the River Warren and its successor, the present Minnesota River. The strike of the knobs is N. 75° W., yet this can not be accepted as determining the direction of the eruptive material; it rather marks the direction of the currents of the eroding stream. Trees and turf cover the surface of the rock, save where the slopes are too steep to retain soil.

The rock is unusually dark colored. It exhibits many spots of a bronzelike hue, which are probably enstatite cleavages, and many dark olive-green markings of irregular contour. In more decomposed places the fresh fractures are spotted with bright green, pointing to the alteration of one or more of its constituents into chlorite. In still other places fresh fractures show that the color of the more massive portion varies to a mixture of dirty, light-brown patches set in a groundmass of dull-green, finely crystalline material, while at the surface the color becomes brown to black on account of the presence of organic matter. Beneath this superficial coating of foreign material the dull-brown color of the abundant limonite results from the proneness to alteration, one of the marked characters of the rock.

The exposures everywhere are badly fractured. Along every seam

and parting plane alteration has extended into the rock. Percolation channels are thus afforded, along which waters have corroded the rock, usually leaving a spongy, cavernous surface. Locally, however, there has been deposited from infiltration calcite in small masses, together with crystalline and crystallized quartz in much greater quantity. The quartz is occasionally amethystine, and clusters of rather small amethyst crystals were seen. The calcite was almost everywhere characterized by a waxy luster and by undulous cleavage planes.

In mineral composition the peridotite is varying. The freshest specimens are composed of enstatite and olivine, with their alteration products, serpentine, chlorite, limonite, and chromite. From this composition it is seen that the original rock was that variety of peridotite called by Wadsworth¹ saxonite, and described by Dathe² some years ago under the name enstatite-olivine rocks from Russdorf, Saxony. The rock of the Minnesota Valley differs from the type described by Dathe chiefly in the parallel (gneissic?) structure of the latter; both rocks are characterized by the predominance of enstatite over olivine and all other constituents, both accessory and secondary. The freshest specimens at hand (sp. 5215, 5731) show in several thin sections an average enstatite content near 40 per cent, while there is less than 10 per cent of olivine. Taking into consideration the secondary contents of the rock, and assuming their origin from their color and textural characters, the following estimate is made of the original mineral composition of this saxonite: Enstatite, 60 per cent; olivine, 35 per cent; all other constituents, 5 per cent; total, 100 per cent. The specific gravity of the rock, the average of four determinations, is 2.827.

Microscopically the enstatite grains are fresh in their central portions and disintegrated around their borders. Rarely are well-defined boundaries seen. Many areas are still large, indicating an originally coarse-grained rock. The color is light brown, the cleavage parallel to the axis *c* is conspicuous, and the separation of the grains is into thin plates, in many places so marked as to give a fibrous habit when the section is cut across the planes. There is no dichroism and the extinction is parallel. This is probably the oldest mineral in the rock.

Next in interest is olivine. This mineral is everywhere surrounded by secondary products. Its position indicates that it was formed subsequent to the enstatite. Many of the grains are included within the enstatite individuals, as Wadsworth showed for the Minnesota enstatite (hypersthene?)-bearing gabbros.³ In every case there is between the two minerals a band of decomposition products partaking of the

¹ *Lithological Studies; a Description and Classification of the Rocks of the Cordilleras*, by M. E. Wadsworth, Cambridge, 1884, p. 125.

² *Neues Jahrbuch für Mineralogie, Geologie und Paläontologie*, by E. Dathe, Stuttgart, 1876, pp. 223-235.

³ Preliminary description of the peridotites, gabbros, and andesytes of Minnesota, by M. E. Wadsworth: *Bull. Geol. Nat. Hist. Survey Minnesota*, No. 2, 1887, p. 59, 62.

nature of a reaction rim. Thus they are never seen in contact. This band resembles in color and textural characters the decomposition products of olivine, rather than of enstatite, as those products have been grouped in the examination of the thin sections. Owing to some local differentiation of which the rock seems to bear indications, olivine might originally have constituted the major portion within small areas, although it now comprises only a small per cent in the very freshest specimens. The grains are rounded and elliptical in shape. Generally several small areas lie clustered in the same crystallographic position, thus indicating that they are all parts of the same original crystal grain. Occasionally the existing grains are penetrated by veinlets of secondary material. This comparative freshness of certain grains may indicate, not any ability to resist decomposition, but rather that the prismatic zone of these individuals lies in the field.¹ The surfaces of the olivine grains generally show that rough appearance due to a high refraction index. Inclusions are rare, and the mineral is unusually free from impurities. This may be due in part to the fact that the portions of the several grains which were once studded with impurities were the first to succumb to alteration and have completely disappeared. (See Pl. XXVII, A.)

The remaining constituents of the rock seem to be secondary. The first among them in importance is serpentine. This mineral flows around the others as a matrix in which the remains of the primary constituents and the crystals of magnetite and other secondary minerals lie embedded. It constitutes nearly half of the entire rock mass in the freshest specimens, and an increasing percentage in the more decomposed, until the whole hand specimen is frequently serpentine. It is everywhere fibrous in structure. Locally it appears as plates across which the extinction shades play in wavelike succession as the field is rotated between crossed nicols.

An opaque mineral is present, which frequently presents the rectangular sections indicating cubic crystallization. In size the individuals seldom exceed 0.025 mm., although clusters are much larger. When crushed the rock affords a considerable quantity of a jet-black, strongly magnetic powder. Careful qualitative tests fail to give reactions for chromium or titanium. The mineral is therefore magnetite. These magnetite crystals occur in the most completely altered portions of the rock. Wherever there are traces of the enstatite or olivine the opaque constituent lies in clusters and dendrites of granular habit. These clusters are crowded to the walls of the percolation canals, and often afford boundaries between the primary constituents and the serpentine. So far as observed, magnetite does not occur within the unaltered primary minerals.

It has already been noted that quartz, in crystallized coatings and clusters of amethysts, is frequently seen along the joints and in the

¹ See Peridotite of Elliott County, Kentucky, by J. S. Diller: Bull. U. S. Geol. Survey No. 38, 1887, p. 12.

more-altered portions of the rock. Thin sections cut from the most-altered hand specimens show that quartz is steadily replacing the more soluble constituents. It occurs in finely crystalline aggregations as veins and tongue-like processes extending into the very interiors of the serpentinous areas. Locally it has replaced all other constituents. It is free from inclusions, and the grains are mutually penetrating. Some very beautiful specimens of vein quartz were seen in which the pyramids of opposite crystals interlocked and the concentric structure of the pyramids was a marked feature of the mineral.

Calcite is very seldom seen in the fresher hand specimens; in the more decomposed it occurs as incrustations of a resinous, yellowish-white mineral upon the surfaces of the joint planes, and microscopically within the rock mass as veins filling the spaces formed by the removal of the olivine material. It is probable that much of the carbonate is dolomite, since magnesia occurs so abundantly in both original constituents, enstatite and olivine, and the pulverized rock is more extensively dissolved in heated than in cold chlorhydric acid. It is in the partially altered rock that the carbonates are found; in those most completely changed quartz seems to be taking the place of all other minerals, both primary and derived.

Chlorite is present in small quantity in the more-altered portions. It presents the usual characters of this mineral developed as a secondary product in ultrabasic rocks, being fibrous in texture and sometimes arranged in rosettelike shapes of radiating needles.

Biotite is present in a few scattered folia, which were too minute for the complete demonstration of chemical or physical characters.

The chemical composition of the freshest specimens of saxonite (sp. 5215) was determined (I) by Mr. Alonzo D. Meeds, in the chemical laboratory of the University of Minnesota. A separate determination (II) of the silica and alumina was made by Mr. F. R. Smith.

Analyses of saxonite from the Minnesota River Valley.

Constituent.	I.	II.
	<i>Per cent.</i>	<i>Per cent.</i>
SiO ₂ (silica)	43.65	43.52
Fe ₂ O ₃ (ferric oxide)	15.94	.....
FeO (ferrous oxide)	5.14	.....
Al ₂ O ₃ (alumina)	6.81	6.81
CaO (lime)	4.86	.....
MgO (magnesia)	12.91	.....
Na ₂ O (soda)	0.43	.....
K ₂ O (potash)	0.52	.....
CO ₂ (carbon dioxide)	1.12	.....
H ₂ O (water)	7.46	.....
Total	98.84	.....

I. Peridotite, var. saxonite. Sp. 5215. Locality, sec: 4, T. 112 N., R. 34 W.

II. Same specimen and same locality as I. A separate determination of the silica and alumina.

By comparison it is seen that the silica content of this saxonite is very near that of the olivine-enstatite rock (saxonite?) found on St. Pauls Rocks,¹ although in its total chemical characters it is close to the picrite of Schriesheim of Baden, analyzed by Fuchs.² The specific gravity of the two is very near that of Fuchs's Schillerfels, being 2.82.

SERPENTINE.

The serpentine is an alteration product of the peridotite, and as the alteration of the latter has already been considered, little need be said of the serpentine. It is, of course, the chief resultant product of the decomposition of the original minerals of the rock. Chlorite, magnetite, finely crystalline quartz, and one or more carbonates are also readily distinguished (sp. 5216, 5733). (See Pl. XXVII, *B*.) Serpentine varies considerably in color, the variation being due to the changing proportions of the accessory minerals. The dark-colored portions are the more compact and heavier. Calcite in unusually resinous habit is a frequent vein mineral in the serpentinous phases of this locality. The specific gravity of one of the bowlders collected in secs. 32 and 33, T. 112 N., R. 33 W., is 3.206.

¹ British Petrography, by J. J. H. Teall, London, 1888, p. 103.

² Schillerfels bei Schriesheim, by C. W. C. Fuchs: Neues Jahrbuch für Min., Geol., und Pet., Stuttgart, 1864, pp. 326-332.

CHAPTER VII.

DIKES.

OCCURRENCE.

From one end of the Minnesota Valley to the other dikes of a heavy, dark-colored basic rock—diabase—cut the gneisses and schists. These dikes, "the igneous filling of fissures,"¹ are usually in vertical position. Exceptionally they come to the surface by following the laminæ of the rocks through which they break, as at Montevideo. Every thickness, from a fraction of an inch to 165 or 175 feet, is shown. As a rule these rock bodies are nearly straight in their course, and they hold their thickness with surprising uniformity. It is extremely rare that one "pinches out" or that it is interrupted by the cutting across it of veins. Intrusions and veins of a granitic type are not here considered.

These dikes, with two or three exceptions, are of finer texture than the gneisses and gabbro-schists in which they occur. Structurally they are considerably shattered, and it is only in the broadest of them that blocks of any size free from joints can be seen. A basaltic structure is frequently evident, with the horizontal columns at right angles to the walls of the inclosing rock. Weathering has not yet attacked them to any marked extent, either on the exposed tops or where the country rock has been broken away on the edges of the dikes.

No products of disintegration are to be seen among the rocks, either in the shape of concentrically weathered blocks on the surface of masses or in comminuted rock débris in depressions. This is due in part, perhaps, to the comparatively recent removal of the loosened blocks, through glacial agencies, as fast as they became loosened in their places in the natural walls. It must be granted that a fraction only of the dikes actually occurring in the valley can be seen in the comparatively small area of rock surfaces in sight above the glacial drift and river alluvium. Those that were seen, and from nearly all of which specimens were taken, in the exploration of the valley are cited on the following page.

¹ *Geology of Wisconsin*, by T. C. Chamberlin, Vol. I, 1888, p. 48.

Dikes in Minnesota River Valley from which specimens were taken.

Location.	Strike.	Specimen number.
T. 111 N., R. 32 W., sec. 22	NE. and SW ..	5191, 5724
T. 112 N., R. 33 W., NE. $\frac{1}{2}$ SE. $\frac{1}{2}$, sec. 34	N. 60° E.	5185, 5199
T. 112 N., R. 34 W., SE. $\frac{1}{2}$ NE. $\frac{1}{2}$, sec. 9	N. 75° W.	5215-5216
T. 115 N., R. 39 W., SW. $\frac{1}{2}$ SW. $\frac{1}{2}$, sec. 1	N. 75° E.	5238
T. 115 N., R. 39 W., SW. $\frac{1}{2}$ NW. $\frac{1}{2}$, sec. 12	N. 65° E.	5280
T. 116 N., R. 39 W., SE. $\frac{1}{2}$ NE. $\frac{1}{2}$, sec. 29	N. 30° E.	5286
T. 116 N., R. 39 W., SW. $\frac{1}{2}$ SW. $\frac{1}{2}$, sec. 34	N. 60° E.	5294
T. 116 N., R. 39 W., NW. $\frac{1}{2}$ SE. $\frac{1}{2}$, sec. 34	N. 60° E.	5295
T. 117 N., R. 40 W., NW. $\frac{1}{2}$ NE. $\frac{1}{2}$, sec. 34	N. 65° E.	5299
T. 117 N., R. 40 W., NW. $\frac{1}{2}$ NE. $\frac{1}{2}$, sec. 34	N. 65° E.	5300
T. 117 N., R. 40 W., SW. $\frac{1}{2}$ SW. $\frac{1}{2}$, sec. 21	NE.-SW	5303
T. 114 N., R. 38 W., NW. $\frac{1}{2}$ NE. $\frac{1}{2}$, sec. 13	N. 30° E.	5368
T. 112 N., R. 34 W., NE. $\frac{1}{2}$ NW. $\frac{1}{2}$, sec. 24	N. 85° E.	5403, 5763
T. 115 N., R. 39 W., NE. $\frac{1}{2}$ NE. $\frac{1}{2}$, sec. 24	N. 55° E.	5419
T. 115 N., R. 39 W., NE. $\frac{1}{2}$ SE. $\frac{1}{2}$, sec. 4	N. 45° E.	5423
T. 116 N., R. 39 W., NE. $\frac{1}{2}$ NE. $\frac{1}{2}$, sec. 32 .....	.....	.....
T. 116 N., R. 39 W., SE. $\frac{1}{2}$ NE. $\frac{1}{2}$, sec. 33 .....	.....	5432
T. 116 N., R. 39 W., NW. $\frac{1}{2}$ NW. $\frac{1}{2}$, sec. 33	N. 40° E.	5440
T. 116 N., R. 39 W., NW. $\frac{1}{2}$ NW. $\frac{1}{2}$, sec. 33	N. 40° E.	5441
T. 116 N., R. 39 W., SW. $\frac{1}{2}$ SW. $\frac{1}{2}$, sec. 34	N. 82° E.	5442
T. 115 N., R. 39 W., NE. $\frac{1}{2}$ NE. $\frac{1}{2}$, sec. 4	N. 5° W.	5443
T. 115 N., R. 39 W., NE. $\frac{1}{2}$ NW. $\frac{1}{2}$, sec. 4	N. 80° E.	5446
T. 116 N., R. 39 W., NW. $\frac{1}{2}$ SE. $\frac{1}{2}$, sec. 34	N. 65° E. ....	.....
T. 116 N., R. 39 W., NW. $\frac{1}{2}$ SE. $\frac{1}{2}$, sec. 34	N. 65° E. ....	.....
T. 115 N., R. 39 W., NW. $\frac{1}{2}$ NW. $\frac{1}{2}$, sec. 3	N. 80° E.	5769
T. 115 N., R. 39 W., NW. $\frac{1}{2}$ NW. $\frac{1}{2}$, sec. 3	N. 80° E. ....	.....
T. 115 N., R. 39 W., NE. $\frac{1}{2}$ SW. $\frac{1}{2}$, sec. 4	N. 80° E.	5446

The average direction of these dikes is as nearly NE.-SW. as can well be estimated, thus indicating the Lake Superior Basin as the point to the northeast toward which they, as a group, seem to trend. Between the valley and Lake Superior lies the great central Minnesota area of hornblende-biotite-granites, with smaller areas of gneisses and schists. Throughout this area, also, there are numerous dikes which, in many of their mineral and chemical characters and in their contact phenomena, are similar to those under consideration. In general direction, too, there is the same NE.-SW. trend in central Minnesota as was noted throughout the length of the Minnesota Valley.

The walls of the dikes present a sharp mineralogical contrast with the contact surfaces of the gneisses and gabbro-schists through which they break. Many slides were examined to discover whether any perceptible effect was produced by these intrusions of plastic basic matter on the containing rocks, but no very considerable effect was seen. The normal freshness of the gneisses and gabbro-schists is maintained throughout the entire zone of contact. There is a deposition of micro-crystalline quartz along the immediate contact, and perhaps a slight kaolinization of the feldspars. Aside from the points noted, the gneisses and gabbro-schists were as greatly altered far away from any

known dikes as they were upon the very zone of contact. The two rocks, the dike and the country rock, are so firmly united that thin sections extending across the contact zone could frequently be made, as Pl. XXVI, A, will show (sp. 5294). Constant watch was kept, in passing these dikes, for some evidence of dynamic action suggested in their contact with other rocks and in their mineral structures. Nothing was seen that pointed to any profound disturbance subsequent to their intrusion. Nowhere was there seen any foliation of the rock itself or any development of foliated minerals, both of which, according to Williams,¹ are produced by dynamic action. Their position is always vertical, save where, as below Montevideo, they break through the gneisses along the lines of least resistance and thus follow, for short distances, the foliation of the rock. Nowhere was the foliated gabbro of such a diabasic type as to be regarded as a formation of similar origin with the contents of the dikes. Everywhere that a contact between the two was seen it proved the structural deformation of the former before the appearance of the latter.

From the foregoing considerations it will be seen that the lithological distinction between the gabbros and the diabases is as clear and undoubted as that between the gabbros and the gneisses.

Around Minnesota Falls and Granite Falls, as will be seen from the list on the preceding page, dikes are rather numerous. Many were seen which were not sampled and are not enumerated in the table. The general direction is NE.-SW. Their breadth varies from a few inches to 40 or 50 feet. They are all harder than the surrounding rocks, and resist weathering much better, and thus, in the low ground where erosion has been accomplished, these rock masses stand in ridges, either continuous or interrupted, which stretch for long distances across the valley and add in no small degree to the billowy aspect—due to unequal erosion of the rock masses—extending over several square miles in this neighborhood. All the dikes are much alike in color, in horizontal columnar structure, and in tendency to conchoidal fracture. There is a variation in texture connected with the breadth of the dike, and considerable difference in the degree of preservation of the original mineral constituents. In some of the dikes the basic constituents have been entirely obliterated, while in others alteration has obtained to only a slight degree.

AGE.

The nonlaminated character of all the dikes seen by the writer in Minnesota suggests that the crustal movements, local displacements, and foldings which were undoubtedly the chief agency in the formation of the schistose character of the other rocks of the region, took place long before the intrusion of the diabases. Another fact, already empha-

¹The greenstone schist areas of the Menominee and Marquette regions of Michigan, by G. H. Williams: Bull. U. S. Geol. Survey No. 62, 1890, p. 206.

sized, that no dikes have thus far been found among the horizontal sandstones and dolomites constituting the widely distributed Cambrian beds of the Northwestern States, places the period of their formation near the time of volcanic activity in the great Lake Superior syncline designated Keweenaw.

GENERAL PETROGRAPHICAL CHARACTERS.

Macroscopical.—These dikes vary in texture more than in structure or in chemical or mineralogical composition. This variation can often be seen as well in the central and marginal portions of the same dike as in two different dikes from extreme portions of the valley. As a rule, the narrow dikes are of firm, compact, and even texture, while the broader ones are correspondingly coarser and more porphyritic in habit. Everywhere the broken surface shows a firm, fresh rock, which rings under the hammer and separates with a conchoidal fracture into sharply angular fragments.

In color all the dikes around Minnesota Falls are dark, some of them almost black. Others take on a greenish hue, as, for instance, the great dike in the lower valley in secs. 23 and 24, T. 112 N., R. 34 W., which, according to the degree of alteration the rock has undergone, becomes in places of a decidedly pea-green color. Other dikes, as in western Granite Falls (sp. 5441), exhibit a color alteration toward brown. This is attained, however, by only a part of the constituents. In the field the darkness and evenness of color and the uniformity of texture enable one to distinguish at sight the dikes from the dark-colored laminated rocks through which they break.

The porphyritic habit of the broader dikes is very clearly shown to the unaided eye. The coarser-textured samples frequently exhibit cleaved surfaces of polysynthetically twinned feldspars from a half to three-quarters of an inch in length, and a general lathlike habit for all the individuals of these minerals. The fresher and more firmly textured dikes show in a less degree this same porphyritic habit.

Now and then are to be seen nests of feldspathic material due to the segregation of the feldspars. A greenish tinge is always seen in the midst of and around these segregations, produced by the alteration to hornblende of the augitic constituent in their immediate neighborhood.

It is true that many phases of texture and mineral composition can be seen. There is a wide range in textural characters. In mineral composition a variation has been traced as wide as the difference between an almost fresh and perfect condition of one of the essential minerals, augite, on the one extreme (Pl. XXV, *B*), and the utter destruction of this mineral and the building up on its remains of clear, fresh individuals of hornblende on the other (Pl. XXI, *B*). Yet there is no evidence at hand to show that these degrees of preservation are in any way due to a difference in the age of the dikes or

to any local conditions surrounding their intrusion.¹ The difference in mineral composition is probably due to unequal weathering. Nowhere in the valley has quarrying enabled one to gather evidence of any more deeply seated alteration.

Microscopical.—In thin section, as well as macroscopically, these dikes present the diabasic type. In places, as in the large dike south of Granite Falls (sp. 5423), a beautiful ophitic structure is seen. In some instances a porphyritic habit, with marked absence of the ophitic structure, is very pronounced. Pl. XXI shows very clearly the two types of diabasic structure exhibited by the rocks in the valley. Nowhere are these rocks entirely free from alteration, although some hand specimens freshly broken appear exceedingly fresh. The feldspars are assuming a more or less distinct kaolinization. The changes of the pyroxene to hornblende and biotite are as pronounced as in the gabbro-schists.

In its ordinary occurrence the feldspar appears in slender, lathlike individuals, either simply or polysynthetically twinned. They were developed very early in the crystallization of the dikes. Great diversity in the position of the individuals exists. Occasionally clusters of the feldspar individuals may be noted, which give to the naked eye the appearance mentioned as porphyritic. These clusters show at times a beautiful twinning of the crystals, as well as series of parallel-placed individuals. The twinning most frequently follows the Carlsbad law. The extinction varies somewhat, thus showing variation in the relations of the axis, as well as modifications in the chemical composition of the mineral constituent. As a rule the smaller feldspar individuals are rather free from inclusions, and in a majority of the specimens gathered even the larger ones contained few foreign bodies. Where inclusions do occur there are, in certain localities, abundant crystals and granules of hornblende gathered in the centers or cores of the larger feldspar areas. This segregation shows that a molecular change of no little importance and significance is going on among the crystalline constituents of these rocks. In other localities the feldspars are loaded with minute granules of a brown color. It is difficult to determine just what these inclusions are; in places they are granular, translucent, and, when taken alone, almost without color; elsewhere, when the granules are larger, they resemble minute particles of the ferric oxide, hematite, scattered through the field. In places the feldspars are partly altered into kaolin or saussurite. Occasionally the former seems to be the mineral formed by the alteration process, and again the latter, thus differing somewhat from the rocks of like nature in the Menominee region of Wisconsin and Michigan.² In a few cases microcline was observed to play a leading rôle. Aside from these

¹Cf. M. E. Wadsworth: Proc. Boston Soc. Nat. Hist., Vol. XIX, p. 2; also Geol. Nat. Hist. Survey Minnesota, Bull. 2, 1887, p. 6.

²Consult further, The greenstone-schist area of the Menominee and Marquette regions of Michigan, by G. H. Williams: Bull. U. S. Geol. Survey No. 62, 1890, p. 138.

instances, where seen in subordinate quantity, its condition and environment are such as to lead to the opinion that it is a secondary product, as has been shown to be the case in the gneisses with which these dikes are associated.

The pyroxenic constituent is largely ordinary augite. Seldom, however, is this mineral fresh and unaltered save in the central portions of the areas. In the few instances where an unaltered grain is to be seen, a green or a pink color prevails in place of the ordinary light brown so characteristic of the mineral elsewhere. In places the individuals are large and constitute a matrix for the porphyritic lath-shaped feldspars, thus forming admirable examples of the ophitic structure. Where the proportion of augite to feldspar is small, the areas are minute and serve simply to fill up the interstices between the feldspar individuals. In the alteration of this mineral the change begins at the margin or along the numerous cracks which in the vicissitudes of time have been produced in the larger individuals. As a rule, hornblende is the direct result of the change, but more rarely biotite is one of the alteration products. In most cases the change, whether to hornblende or biotite, or to both, has introduced other minerals of secondary origin, the first of which is quartz in minute and clustered granules. Paramorphic hornblende is not produced by the alteration; neither is pseudomorphic hornblende a conspicuous feature of the change. To all appearances the resulting minerals encroach on the feldspars as well as on the pyroxenic constituents. Only rarely is the axial position of the original grains perpetuated in the secondary products—a phenomenon found in some instances in the associated gabbro-schists.

In the various stages of alteration from the rocks containing the clear and nearly fresh augite to those bearing fresh-looking green hornblende only, the whole cycle of changes from diabase to diorite is clearly illustrated. Only a step is lacking to show the evolution of the hornblende-schists. That step is the change brought about by mashing.

Quartz is found in nearly every dike. Nowhere was it seen as a porphyritic separation, as is the case in a few localities in Stearns County, Minnesota, but always as a secondary product accompanying the metamorphic changes in the rocks. The grains are very minute; they polarize brightly and are almost free from inclusions. In places they are clustered, suggesting miniature lenticular or gash veins of quartz. The vermicular quartz so abundant in all the gneissic rocks of this valley is usually absent in the dikes. In those samples where hornblende and biotite as alteration products occur in particularly large and pronounced individuals, quartz grains appear as a prominent portion of the intercrystalline material.

Accessory minerals, aside from those of a secondary origin, are comparatively obscure and unobtrusive. Both magnetite and pyrite are present, usually in rounded grains or clustered masses. Menaccanite

(ilmenite) also appears at times, surrounded by an encircling band of titanite. Occasionally numberless needles of apatite are to be seen.

The chemical constitution of the dikes has not been carefully studied. A determination of the silica in a specimen (5421) from Minnesota Falls showed 52.01 per cent. This is probably an average silica content of these basic rocks. It differs little from the silica content of similar dikes in central and northeastern Minnesota and northern Wisconsin and Michigan.

Passing to matters of detail and of a certain local interest, we note the following more special characters of the dikes already discussed in a general way.

MORTON DISTRICT.

In sec. 19, T. 112 N., R. 33 W., and secs. 23 and 24, T. 112 N., R. 34 W., lies a series of knobs stretching nearly east and west (see Pl. V). These knobs constitute a part of by far the largest dike seen in central and southwestern Minnesota. The width is from 165 to 175 feet, and the height of the knobs varies from 10 to 30 feet above the flood plain. The country rock is the hornblende-biotite-gneiss so characteristic of the Fort Ridgely district. So far as could be noted at the time of the visit, neither the texture nor the mineral composition of the gneiss was modified by contact with the intrusive. The dike stands vertical. Several cases of marked slickensides were noted where a readjustment had been effected between the dike and the gneiss. Texturally the dike is of medium grain, finer at the borders than toward the central portion, but occasionally carrying porphyritic feldspars. Little tendency to amygdaloidal structure was noted, and this near the contact of the gneiss.

The color of the rock is greenish black. The fracture is sharply conchoidal, and the rock rings under the hammer. Weathering corrodes it but slowly, the most perceptible result being a yellowing of the surface through the change of the iron pyrites to a hydrous ferric oxide.

In mineral composition this rock is a partially altered diabase or diabase-porphyrity. The feldspar is plagioclastic, lying in lathlike forms. The porphyritic areas resolve into more or less altered segregations of the lathlike forms instead of exposing broad, polysynthetically twinned plagioclases, as in the gabbro-schists. The individuals are comparatively free from primary impurities, but kaolinization has crept in to a considerable extent in some cases. The segregations mentioned decompose into a fibrous mineral of a slightly green color, with parallel extinction, probably saussuritic in composition.

The augite is more or less altered, and everywhere lies between the lathlike feldspar individuals. Where fresh a light-brown color prevails. The angle c varies from 37° to 43° . Alteration has nearly everywhere set in, resulting, first, in green hornblende, partly massive and partly fibrous, and, second, in biotite. The process has not proceeded far enough to give distinct and individualized forms to the resultant

minerals, except near the surface, where the alteration has gone so far as almost to obliterate the augite individuals.

Magnetite and pyrite occur in grains of varying size and shape, not as a rule of great size nor of any regularity of form. Skeletonlike aggregations of pyrite are sometimes very noticeable. Epidote and apatite are both disclosed by an inspection of thin sections. The latter is present in some portions of the dike in numerous long, slender, needle-shaped crystals, frequently broken.

Quartz as a resultant of the alteration processes rather frequently appears in brightly polarizing areas. As a rule these areas are not large, and they lie in the most-altered portions of the rock. Surface weathering is especially effective in developing this mineral, which is deposited in the contact areas between the inclusions and the normal rock. It extends into both portions, filling interstices in the diabase as well as forming the outer zones of the inclusions themselves, and by degrees gives place in the feldspars to the kaolinic alteration product. In these situations the quartz throughout large masses of the rock has arranged itself in the same crystallographic directions, thus extinguishing simultaneously in large areas, even though, as appears in the section, the different portions of quartz be entirely separated by other minerals. Pl. XXVI, *B*, is an effort to show this intercalated quartz as it is exhibited in specimen 5400.

VICKSBURG DISTRICT.

In the Vicksburg district (see Pl. VIII), in the area designated "rock barrens" by the land surveyors, there are several dikes. One of them, in places 40 feet wide and having a direction N. 30° E., lies exposed at several points in secs. 12 and 13, T. 114 N., R. 38 W. The color is a mixture of green and white. Weathering has changed the surface to a dull, dirty brown or reddish brown. This dike is of medium coarseness. The texture is distinctly diabasic. This and the narrower neighboring dikes are considerably shattered.

The leading mineral constituents are a plagioclase feldspar and one or two pyroxenes. At the surface the feldspar is so greatly altered that the extinction angle can be read in only a portion of the individuals. This extinction points to the anorthite end of the feldspar series. The usual twinning phenomena were noted. The product resulting from the alteration of the feldspar seems to be kaolin. The pyroxene is so completely altered to hornblende that the optical characters of this constituent could not be well determined; 39° marked the extinction of one small core, which placed that individual in the category of ordinary augite. Green hornblende is the leading product resulting from the breaking up of the pyroxene. It is in places developed into well-formed individuals, some of which are strongly twinned. In places the hornblende individuals, as well-developed plates, lie in a matrix of clear secondary quartz, and again a decidedly fibrous condi-

tion prevails, and quartz may or may not be present. A few small areas of biotite seem to spring from the alteration of the hornblende. Quartz is scattered throughout the rock as interstitial matter, generally taking the place of the feldspars. Occasional small areas are pegmatitic. Magnetite is present in small, scattered grains and crystals. Apatite needles are rather numerous, although small.

GRANITE FALLS DISTRICT.

In the Granite Falls district (Pl. X) there are a large number of dikes. Among them are those which are ophitic and very fresh, and others which have lost all their pyroxenic constituents through alteration into hornblende. These last are simply diorite dikes. No geographical classification is possible, since the degree of alteration seems to depend in large measure on the width of the dike and the conditions of rock association under which it occurs.

The two dikes which represent most perfectly the ophitic structure lie the one on the north side of Granite Falls (sp. 5286), 1,100 paces N., 100 paces W., sec. 29, T. 116 N., R. 39 W., and the other to the south of Granite Falls (sp. 5423), 1,000 paces N., — paces W., sec. 4, T. 115 N., R. 39 W. The former has a width of 40 feet and a course N. 30° E. The latter is at least 25 feet wide and runs N. 45° E. While the texture of these two dikes is medium it is coarser than that of others in this district. The color is dark green to black. On the borders of the dikes there are traces of an amygdaloidal structure in the occurrence of vesicles. Rarely porphyritic crystals of plagioclastic feldspar are found. The augite occurs in large areas from 2 to 5 mm. across (see Pl. XXV, B, from sp. 5286, sl. 2241). Their borders are somewhat roughened by alteration and the intrusion of secondary hornblende. Freshly fractured surfaces of the rock show numerous cleavage planes of the augite thickly interwoven with the cleaved lathlike crystals of the feldspar. The spaces between these augite surfaces are filled with a finely granular matrix, which lacks the bright reflection just mentioned and is of a green color. These reflecting surfaces seem to be identical with those described by R. Pumpelly in the melaphyr or "greenstone" extending along Keweenaw Point and stretching southwestward.¹ The structure has been seen by the writer in many rocks of the Northwest, including diabases, gabbros, and even granites. Aside from the lathlike labradorite crystals which penetrate them in every direction, the augite crystal areas are singularly free from inclusions. There are fractures which to a greater or less extent serve as alteration zones and facilitate the progress of mineral changes.

The feldspar crystals, which are labradorite or very near it in optical characters, are filled with brown, dustlike inclusions. Their distribution through the feldspar crystal is not uniform, but they are

¹ Metasomatic development of the copper-bearing rocks of Lake Superior, by R. Pumpelly. Proc. Am. Acad. Arts Sci., Vol. XIII, 1878, pp. 280-281; also Geol. of Wisconsin, Vol. III, 1880, p. 38.

clustered in certain portions, where they impart a decided brown color to the mineral. Another inclusion which seems to be quite common in the feldspars is finely granular augite, which was apparently caught up in the crystallization of the rock. The boundaries of the feldspars are sharp and smooth planes. The shreds and prismatic blocks of augite everywhere seem to penetrate them. This is more particularly true of the ends and diagonal edges of the feldspars than of their prismatic surfaces.

Olivine is present, but only a few central cores remain of what was once no inconsiderable constituent. The rough surface, bright polarization colors, and optical extinction show the nature of these cores. They are bounded by a bright-green hornblendic alteration product which is radially developed around the cores. Associated with the hornblendic product is a black, opaque, granular material, probably an oxide of iron, which in places is developed in æstivated forms, due to the contact of the granules. Magnetite in large crystals and granular areas is a comparatively frequent mineral. Biotite was seen in all the slides examined, doubtless occurring as a secondary product.

Entering the neighborhood of Minnesota Falls and Granite Falls from the south, one meets the first dike to the south of Minnesota Falls, in sec. 12, T. 115 N., R. 39 W. This dike (sp. 5280), about 20 feet in width, breaks vertically through a gabbro-schist. The feldspars were lath-shaped individuals; the original boundaries of many are now obliterated, and the polysynthetic twinning can no longer be seen. Nowhere is augite visible, but its place has been taken by hornblende and biotite as secondary products. The hornblende occurs in fine granules, lying sometimes in parallel position, but usually scattered in all directions. The proofs of the secondary nature of the hornblende do not lie in these slides only; they can be seen in the rocks of the locality taken as a whole. At this place the gabbro-schist cut contains much fresh pyroxene, and yet this mineral has utterly disappeared in an intersecting dike. Magnetite, epidote, and pyrite are present. The last two, and doubtless much of the first named, are secondary minerals.

Just across the river, in secs. 2 and 11, and almost due north from the dike just described, extend other dikes, somewhat broader and coarser textured (sp. 5419). The direction is N. 44° E. Mineralogically they are almost precisely like the dike south of the river (sp. 5280), differing chiefly in their coarser texture, in the larger proportion of secondary biotite, and in the skeletonlike segregations of pyrite. The alteration of the pyroxene into hornblende has proceeded far enough to change to some extent the sharp boundaries between the feldspar individuals and their basic neighbors.

In sec. 34, T. 116 N., R. 39 W., East Granite Falls, around the railway station and the grain elevators, and stretching southwestward to the

river, are several occurrences of dikes. One of them appears to be of considerable width, at least 30 or 40 feet. (Sp. 5294.) Its direction is W. 30° S. The central part is rather coarse textured, firm, and fresh, while along the contact with the gabbroid rock it is rather finely crystalline. Another dike (sp. 5295), exposed in several places near the Pillsbury grain elevator, is of nearly equal extent. An examination of the rocks constituting these dikes shows the feldspars to be somewhat altered. They carry some small grains of hornblende, and are literally colored brown by the numberless granules, which could not be resolved with an immersion lens. Their color and the general aspect of the rock lead to the view that they are the same substance which has been mentioned as occurring in the fresh, ophitic, diabase dikes. The augite has entirely disappeared, and its place is now occupied by hornblende lying in fine and irregularly distributed grains. In places these grains of hornblende include numberless minute black particles. Where biotite is seen, it lies near the corroded particles of iron pyrites.

In the south side of this same section (34) lie other dikes having the same general macroscopic characters as those named. A slide made of the contact material between one of these dikes and the country gabbro-schist shows a very sharp contact (sp. 5294). The gabbro-schist and the dike show an entire alteration of the pyroxenic constituents into finely granular hornblende and into an abundance of fresh-looking plagioclasic feldspars. The dike material is finely crystalline and the plagioclase is in part porphyritic. A very fine texture is noticeable along this contact, which does not appear in the middle of the dike, and a belt of finely granular quartz forms an almost complete zone of separation between the dike and the country rock (see Pl. XXVI, A).

Along the river's edge and near the highway which leads out of Granite Falls toward the northwest are several dikes, some of considerable width. They are seen in that portion of sec. 28 lying south of the Minnesota River, and along the northern border of sec. 33. In the last-named section three of four dikes are nearly parallel as they stretch across the brow of a hill. Their general direction seems to be S. 40° W. Several minor dikes show considerable variation from this course. In mineral composition they are all essentially the same.

In Granite Falls a narrow dike 5 inches wide was sampled (sp. 5432), which macroscopically shows a distinct porphyritic structure. A microscopic examination shows that this appearance is due to nests of hornblende granules within a matrix of plagioclase, hornblende, and biotite. In their distribution these granules mark the form of some preexisting crystals which might have been olivine, thus presenting a rock like that at Sauk Rapids, where olivine crystals are still clear and distinct in a porphyritic rock occurring as a narrow dike in the hornblende-biotite-granite of the Sauk Rapids granite quarry.

Between the fresh dikes and the much-altered ones above described

are many intermediate stages, in which the feldspars are tinged with alteration and the augites show hornblende around their borders and along cracks within the grains. The phases of alteration, while varying slightly in some details, have their broader characters in common, and represent every stage from the fresh augite to the clear hornblende.

MONTEVIDEO DISTRICT.

Around Montevideo (see Pl. XI) there are several dikes of some lithologic interest. They lie in the bottoms south of the railroad track, in secs. 20, 21, and 34, T. 117 N., R. 40 W. They are of diverse widths and vary in degree of preservation. With a single exception, so far as observed, they stand in vertical positions in the rocks. This exception is in a railway cut in sec. 20, where a dike a few inches in width follows the bedding of the red acidic gneiss of the district.

Where these dikes are narrow, as in sec. 34 (sp. 5299, 5300), they show the total disappearance of augite and the plentiful occurrence of needles of apatite in every part of the section. The alteration products of the augite are hornblende and biotite, nearly in the proportion of 2 to 1 in the slides examined. While many localities show the direct formation of hornblende alone from the augite, these rocks exhibit a remarkably even distribution of the biotite, not only around the hornblende areas but within them as well.

In the broader dikes (sp. 5303) the individuals of all the mineral constituents are much larger. The feldspars, which frequently lie in nests of twinned forms, are loaded with minute granules of hornblende scattered as an impurity through their central portions. These hornblende granules all seem to lie in the same crystallographic direction in any given feldspar. A characteristic feature of these feldspars is the brown color which appears in almost every section. In places—for instance, where the hornblende granules appear in their cores—the brown color is exceedingly slight, and as a rule the feldspars are more mashed around the borders of the areas, although this condition can not be clearly defined. Twinning in very striking forms is shown in the larger feldspars, combinations after the pericline and albite law being frequent. A zonal structure is conspicuous in many of them. It appears to be of two kinds: first, a structure due to interruptions in the growth of the crystal grains; and, second, where additions of a secondary nature were made to the original feldspar individuals after the consolidation of the rock and during its alteration. Occasionally the feldspar areas show the presence of kaolinic material. The augites have begun to change to hornblende, as their rims of finely crystalline, green material clearly show. In places the alteration is complete. (See Pl. XXV, A.) Olivine is not present, and no cores of that mineral were noticed, although many areas of secondary material occur, particularly in that part of the dike near the contact. These areas are

small, and in all cases are composed of a radiating viriditic mineral having the general characters of hornblende and in every respect identical with the rims around the olivine cores of the two ophitic dikes of Granite Falls. Little biotite is seen. Pyrite is present, but not in abundance.

EXCEPTIONAL DIKES.

Besides the diabases described in the foregoing paragraphs, there were noted two or three areas of somewhat different rocks. Although these exposures are of the diabasic type, they are so different from the normal dikes of the valley that they will be considered separately.

On the south side of the river, in secs. 14 and 15, T. 112 N., R. 34 W., there are large masses of this rather coarse-grained rock. A gneissic structure is pronounced. This structure is developed, not through any noticeable parallelism in the position of the constituent minerals, but by a distinct segregation of these minerals into bands or laminæ extending considerable distances through the rock.

The field relations of this belt of rocks are very obscure. No contact with other rocks on either side could be seen. At the surface the rock is considerably decomposed, and the reddish hue of much of the feldspars is imparted to it. The weathering produces a rough, uneven surface. While some contortion is noticeable, the general strike of these masses is NE.-SW., with a dip frequently as high as 80° S. Scattered through this rock are inclusions of material more or less feldspathic than the average. To the naked eye the rocks seem to be unusually free from accessory minerals. Here and there small nests of pyrite can be seen, and occasionally a porous condition near the surface points to the dissolving and carrying away of some mineral more readily acted upon than most of the constituents.

While the texture of this rock is medium, there is a peculiar and apparently secondary structure running through it, seen in every exposure. This consists chiefly in the presence of broad, thin leaves of the hornblende. This mineral in its formation seems to have been arranged with many of its individuals having their axes, *c*, in a common direction within considerable areas, 1 and 2 inches across, thus giving the impression of large individuals. This impression is intensified by the reflection of the light at the same angle from a large number of small grains breaking and cleaving in the same plane. Their composite character can be best seen where the feldspars predominate, since color contrasts serve to bring out more sharply the outlines of the areas. The fresh fracture, when studied with low power, has a decidedly granular appearance, with the grains all presenting their cleavage planes at precisely the same angle. Between these grains can be detected the feldspars, the epidote grains, and, in the more weathered portions, biotite folia. While the length and breadth of these segregations are considerable, they are very thin. Looked at on edge,

they are mere dark lines through the field of light-colored constituents. This condition of itself would give a lamination to the rock, did all these tabular segregations lie in one general direction, which is not the case.

While these are not porphyritic individuals of hornblende, they seem to have a relation to the arrangement of the augite peculiar to certain eruptive rocks. This arrangement suggested to Pumpelly,¹ as he studied the melaphyre of Lake Superior, the significant term "luster-mottling." This structure has since been observed in contemporary diabases and gabbros, and in gneissic rocks of still greater age.²

A slide made from the lighter-colored bands would show probably 75 per cent of feldspar and epidote, the chief alteration product of the feldspar, and one from the darker band an equal proportion of hornblende. A greenish color pervades many of the feldspar individuals, especially those of the laminae poor in hornblende. This is due, doubtless, to the epidote present. In places, too, the hornblende itself has this pale-green tone. Where there are variations toward a veinlike character, the feldspars are red in color and the hornblende exhibits well-formed crystals.

The only exposure of these exceptional dikes noted on the north side of the river is in the bottoms in sec. 34, T. 112 N., R. 33 W. The area is small, lying beside a small circular lake and not more than 15 feet above the surface of the water. While the rock is generally massive, it shows in places a distinct lamination, due to the segregation of the darker-colored constituents into bands of varying thickness and varying distances apart. In other places segregations of spherical shape occur; these are of a lighter color and somewhat harder than the body of the rock, so that they resist weathering better and thus stand out in knobs. While the mass is somewhat shattered, it is much less so than are the normal dikes of the valley.

The microscopic characters of the exposures are those of very much altered rocks. The feldspars are so far altered to kaolin and epidote that near the edges of three or four individuals only could the extinction angle of the labradorite group be made out. The diabasic structure is seen, although in some sections a greater breadth is noticed than in the feldspar individuals of the ordinary dikes of the valley. In many cases crystal outlines occur, or even perfect porphyritic crystals showing the prismatic, pyramidal, and pinacoidal faces. In the gneisses, as has been stated, there are frequently secondary feldspars, doubtless resulting from the degradation of the primary ones. Here, however, the secondary minerals are in no observed instances feldspars. As a rule the borders of the feldspar crystals are in a much better state of

¹ Metasomatic development of the copper-bearing rocks of Lake Superior, by R. Pumpelly: *Proc. Am. Acad. Arts Sci.*, Vol. XIII, 1878, p. 260. Lithology of the Keweenaw system, by R. Pumpelly: *Geol. Wisconsin*, Vol. III, 1880, p. 33. Preliminary description of the peridotites, gabbros, diabases, and andesytes of Minnesota, by M. E. Wadsworth: *Bull. Geol. Nat. Hist. Survey Minnesota*, No. 2, 1887, p. 107.

² The copper-bearing rocks of Lake Superior, by R. D. Irving: *Mon. U. S. Geol. Survey*, Vol. V, 1883, p. 73. *Ibid.*, p. 42. Notes of a geologic excursion into central Wisconsin, by C. W. Hall: *Bull. Minn. Acad. Nat. Sci.* Vol. III, No. 2, p. 25.

preservation than are their centers, a fact of very wide application among the crystalline rocks of the Northwest.

Quartz is reasonably abundant. Everywhere it is a secondary mineral, free from inclusions and very limpid. It is in pegmatitic forms, occupying interstices between the feldspars, or in granular condition it forms the lenticular fillings seen between the biotite folia. In the first-named position it exhibits sharply marked boundaries, and all the different areas over a considerable surface lie in the same crystallographic position and extinguish together. This is illustrated in Pl. XXVI, *B*, from a thin section cut from specimen 5400. The lenticular fillings are almost as frequent as the areas of biotite. They are wedged in between the folia and oftentimes stretch them to a considerable extent. In places other minerals serve as such filling, particularly epidote and calcite, but these minerals in this situation are rare as compared with quartz. While these fillings are granular, the grains very generally extinguish parallel with the biotite.

Of the basic constituents in the slides examined, augite remains in one or two small cores only, surrounded by secondary hornblende. Many areas of this last-named mineral containing no augite show by the granular and impure condition of their central portions that they are of secondary origin, and the evidence of scores of specimens taken throughout the valley points to preexisting augite or diallage individuals from which the hornblende was derived. In addition to the larger areas mentioned, many small individuals of hornblende lie scattered about. These may arise from the transfer of material during the alteration of the rock.

Besides the hornblende mentioned as an alteration product, chlorite is rather abundant. It occurs in clustered areas of radial, fibrous spherules, which lie in proximity to the hornblende areas and the epidote masses alike. Other areas are found in the midst of the decomposed feldspar individuals. Both in its occurrence here and in its arrangement in the rock, the chlorite seems to unite this rock closely to the gneissic rocks figured from Tracy's place, only 3 or 4 miles away on an air line. (Pl. XVII, *A*.)

Epidote is an alteration product of considerable importance in these rocks. It is probably derived in large part from the decomposition of the feldspars. These, as has just been stated, belong chiefly to the labradorite type, thus containing sufficient lime for the formation of the epidote and the small quantity of calcite present. While much of the epidote lies within and around the changed feldspar areas in a way to suggest its origin from that mineral, as maintained by Chester in his description of the Delaware gabbros,¹ and by Williams in his work on the gabbros in the neighborhood of Baltimore,² that portion

¹ The gabbros and associated rocks in Delaware, by F. D. Chester: Bull. U. S. Geol. Survey No. 59, 1890, p. 25.

² The gabbros and associated hornblende rocks occurring in the neighborhood of Baltimore, Md., by G. H. Williams: Bull. U. S. Geol. Survey No. 28, 1886, pp. 31-32.

of the epidote which occurs in largest individuals and in strongest color is more intimately associated with the hornblende in situation and possibly in derivation.

No analysis of this rock as a whole, or of any of its constituent minerals, was made, so that no considerations based on its composition can be stated. However, taking the analyses of many samples from the tables in Dana's System of Mineralogy,¹ we glean the following facts: The average per cent of calcium oxide, CaO, in the augite of metamorphic and eruptive rocks, computed from the twenty-three analyses given, is nearly 22 per cent. The average of seven analyses of hornblende gave slightly over 13 per cent of calcium oxide, which leaves an excess to supply the epidote, after furnishing all necessary for the hornblende in the change of augite into hornblende, which is assumed. Nowhere are the individuals of epidote of large size, but everywhere they are granular. Twinning striæ were not seen. In no other rock of the valley was so large a proportion of the mineral epidote observed, and in no other examined was the feldspathic constituent so completely obliterated as in this, save, perhaps, in those gneisses of Redwood Falls and Birch Cooley where entire rock masses have been converted into an impure kaolin.

Calcite also occurs in this rock. Its characters are those usually seen in this mineral in the altered crystalline rocks. While sometimes it may be a filling for primary or secondary cavities² in normal eruptive rocks of even very ancient age, as in the Keweenaw and associated rocks of the Lake Superior region, in this case it plainly fills interstices between the existing minerals which have been formed by the alteration of the original plagioclases and pyroxenes. It most frequently occurs around the segregated hornblende, chlorite, and epidote areas, a circumstance which strongly suggests that the larger part of it was formed by the alteration of the augite. Such a change Pumpelly noted among the melaphyres of Lake Superior as long ago as 1878.³ Occasionally twinning striæ appear, but they are comparatively rare. The mineral, as a rule, is very finely granular.

Calcite, as a decomposition product in these rocks, occurs also in the midst of the feldspar areas. Its characters there are precisely those named in interstitial situations. As a result of alteration this mineral has been seen almost nowhere else in the valley except in rocks of the same general character south of the river. Its rarity confirms the assertion of Rosenbusch, who regards it as an alteration product from lime silicates.⁴ A few small crystals of apatite are present.

The light-colored spherical nodules mentioned as included in places in this rock appear to carry a much smaller proportion of hornblende

¹A System of Mineralogy, by J. D. Dana, 5th ed., 1868, pp. 218, 238.

²Preliminary description of the peridotites, gabbros, etc., of Minnesota, by M. E. Wadsworth: Bull. Geol. Nat. Hist. Survey Minnesota, No. 2, 1887, p. 82.

³Metasomatic development of the copper-bearing rocks of Lake Superior, by R. Pumpelly: Proc. Am. Acad. Arts Sci., Vol. XIII, p. 268.

⁴Mikroskopische Physiographie der Mineralien und Gesteine, by H. Rosenbusch, 3d ed., 1892, Vol. I, p. 404.

and biotite than the main mass of the rock. The feldspar in these nodules is considerably fresher than elsewhere, frequently showing the twin striation with sufficient clearness for measurement, and the epidote is much more thickly scattered throughout the mass. Calcite is very infrequent in these nodules. Magnetite and pyrite are scarcely seen.

In the village of Cottonwood, T. 113 N., R. 40 W., the boring of an artesian well was attempted in 1895. At a depth of 280 feet granite rocks were reached. These were penetrated 190 feet. At some point within this distance a band of dark-green, finely textured rock was bored through. One piece, $3\frac{1}{2}$ inches long, was brought up by the slush bucket (sp. 5768). Its surface has a decidedly greasy feel, but a rough fracture is disclosed by breaking. Its specific gravity is 2.85.

Microscopically the rock is an altered diabase. The two principal constituents, labradorite and augite, still remain in fragments sufficiently large and fresh for identification. The augite has a light-brown color, extinguishes at an unusually low angle, and is largely altered into chlorite, hornblende, and associated products. The feldspars are labradorites, with a prevailing low extinction, indicating the presence of soda, an indication borne out by the presence of a suassuritic mineral among the products of alteration. Magnetite is plentiful, with its clearly defined crystal contours.

PLATE XVI.

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PLATE XVI.

Fig. A. Granite-gneiss, a block $3\frac{1}{2}$ by 4 inches, from the Ortonville quarries.

The light pink represents quartz with the color of underlying feldspar seen through the transparent grains; the dark pink the second feldspars; the black the few scattering folia of biotite with, rarely, grains of secondary hornblende.

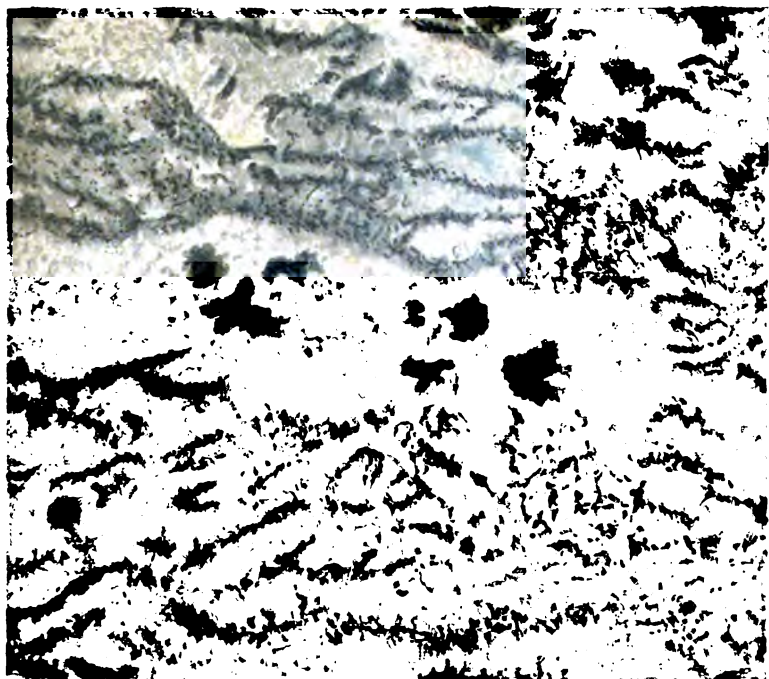
Fig. B. Contorted hornblende-biotite-gneiss, a block $3\frac{1}{2}$ by 4 inches, from the quarries at Morton.

The white represents the quartz and a portion of the feldspars; the pink that portion of the feldspars slightly stained, and the black biotite and hornblende in segregations and bands, with smaller grains in places more evenly distributed among the quartz and feldspars.

See p. 73.



(A)



(B)

(A) GRANITE - GNEISS

TORTORTED HORNBLLENDE - BIOTITE - GNEISS

PLATE XVII.

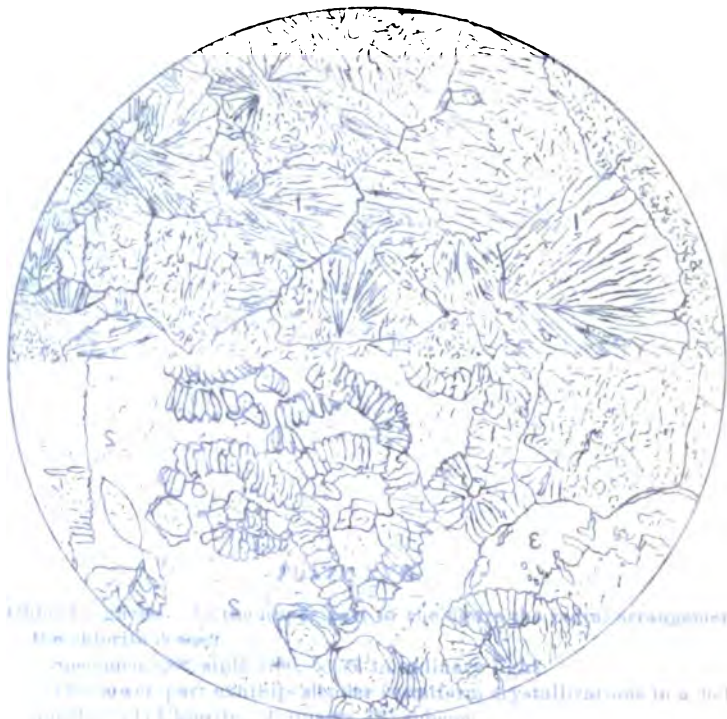


Fig. 1. The same as Fig. 1, but in a different arrangement.

The structure is seen

in a section of a single grain of a crystalline rock.

The lower part of the section shows a crystalline rock in a field

of grains (1) Chlorite, 2 quartz, 3 amphibole.

Specimen 5720, shown in Fig. 1.

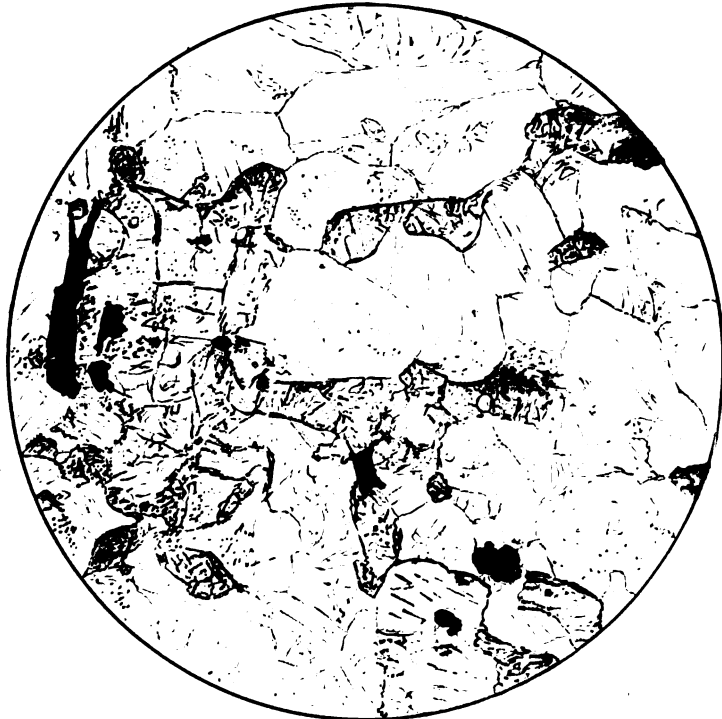
See p. 36.

A fresh mineralized structure is shown.

1. Amphibole, 2. quartz, 3. chlorite, 4. garnet, 5. biotite, 6. zircon, 7. apatite, 8. calcite, 9. pyrite, 10. magnetite, 11. hematite, 12. ilmenite, 13. rutile, 14. titanite, 15. zircon, 16. apatite, 17. calcite, 18. pyrite, 19. magnetite, 20. hematite, 21. ilmenite, 22. rutile, 23. titanite, 24. zircon, 25. apatite, 26. calcite, 27. pyrite, 28. magnetite, 29. hematite, 30. ilmenite, 31. rutile, 32. titanite, 33. zircon, 34. apatite, 35. calcite, 36. pyrite, 37. magnetite, 38. hematite, 39. ilmenite, 40. rutile, 41. titanite, 42. zircon, 43. apatite, 44. calcite, 45. pyrite, 46. magnetite, 47. hematite, 48. ilmenite, 49. rutile, 50. titanite, 51. zircon, 52. apatite, 53. calcite, 54. pyrite, 55. magnetite, 56. hematite, 57. ilmenite, 58. rutile, 59. titanite, 60. zircon, 61. apatite, 62. calcite, 63. pyrite, 64. magnetite, 65. hematite, 66. ilmenite, 67. rutile, 68. titanite, 69. zircon, 70. apatite, 71. calcite, 72. pyrite, 73. magnetite, 74. hematite, 75. ilmenite, 76. rutile, 77. titanite, 78. zircon, 79. apatite, 80. calcite, 81. pyrite, 82. magnetite, 83. hematite, 84. ilmenite, 85. rutile, 86. titanite, 87. zircon, 88. apatite, 89. calcite, 90. pyrite, 91. magnetite, 92. hematite, 93. ilmenite, 94. rutile, 95. titanite, 96. zircon, 97. apatite, 98. calcite, 99. pyrite, 100. magnetite, 101. hematite, 102. ilmenite, 103. rutile, 104. titanite, 105. zircon, 106. apatite, 107. calcite, 108. pyrite, 109. magnetite, 110. hematite, 111. ilmenite, 112. rutile, 113. titanite, 114. zircon, 115. apatite, 116. calcite, 117. pyrite, 118. magnetite, 119. hematite, 120. ilmenite, 121. rutile, 122. titanite, 123. zircon, 124. apatite, 125. calcite, 126. pyrite, 127. magnetite, 128. hematite, 129. ilmenite, 130. rutile, 131. titanite, 132. zircon, 133. apatite, 134. calcite, 135. pyrite, 136. magnetite, 137. hematite, 138. ilmenite, 139. rutile, 140. titanite, 141. zircon, 142. apatite, 143. calcite, 144. pyrite, 145. magnetite, 146. hematite, 147. ilmenite, 148. rutile, 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(A)



(B)

JULIUS BIEN & CO. N.Y.

(A) CHLORITIC GNEISS

(B) HYPERSTHENE GABBRO

PLATE XVII.

Fig. A. Chloritic gneiss. In the upper part of the figure the radial arrangement of the chlorite is seen.

Specimen 5206, slide 1780, $\times 55$, in ordinary light.

The lower part exhibits slender vermiform crystallizations in a field of quartz. (1) Chlorite, (2) quartz, (3) sphene.

Specimen 5729, slide 9478, $\times 250$.

See p. 59.

Fig. B. A fresh unaltered hypersthene-gabbro.

(1) Anorthite-labradorite feldspar, very fresh; (2) hypersthene, scarcely altered; (3) small, scattering folia of biotite.

Specimen 5335, slide 2263, $\times 100$.

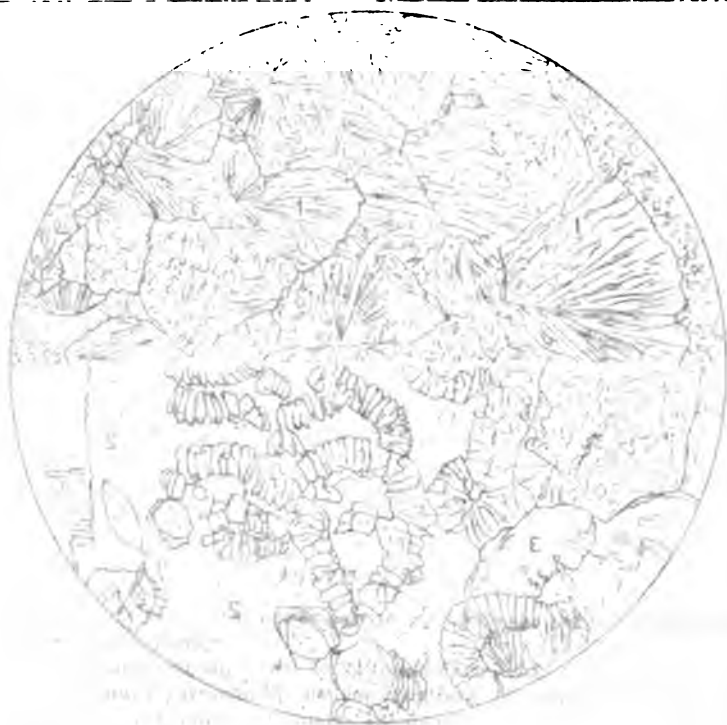
See pp. 91, 95.



(A)

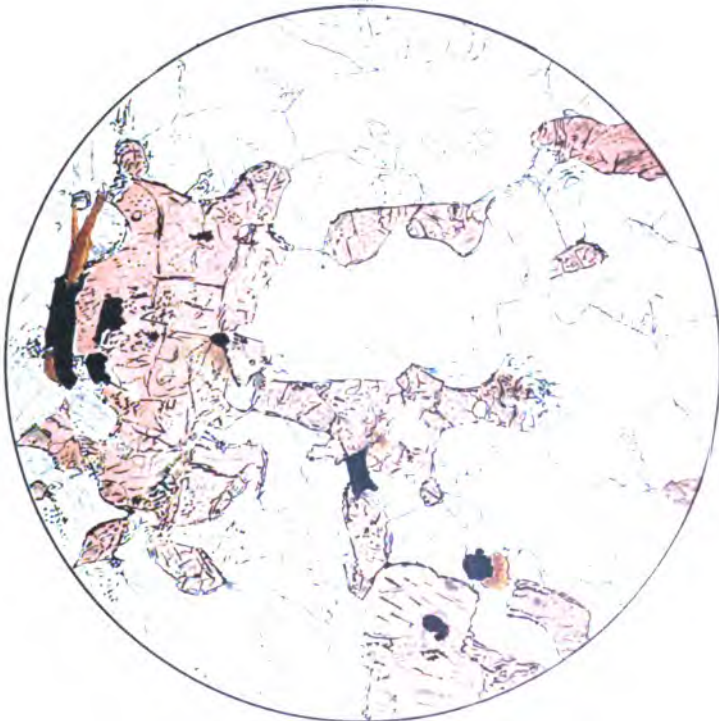


(B)





(A)



(B)

(A) CHLORITIC GNEISS

(B) HYPERSTHENE - GABBRO

PLATE XVIII.

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PLATE XVIII.

Fig. A. Hornblende-biotite-granite-gneiss. Muscovite, apparently formed by the alteration of an albite inclusion in microcline.

(1) A microcline individual much larger than the entire field; (2) an albite inclusion entirely surrounded by the microcline individual; (3) muscovite within the albite and apparently derived from its decomposition; all portions extinguish together; (4) other areas of muscovite; (5) biotite.

Specimen 5338, slide 2265, $\times 53$, in polarized light.

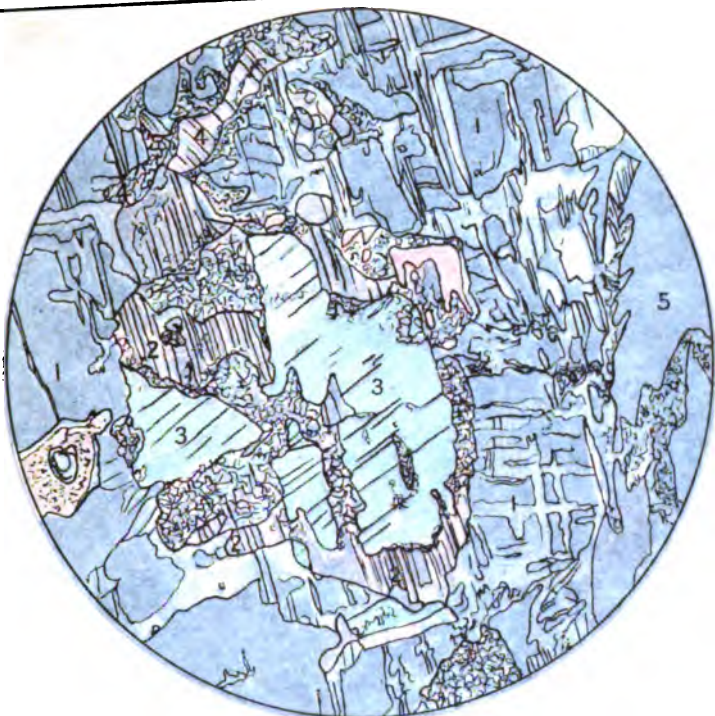
See p. 54.

Fig. B. Hornblende-biotite-gneiss. Vermicular quartz, within an area of albitic feldspar.

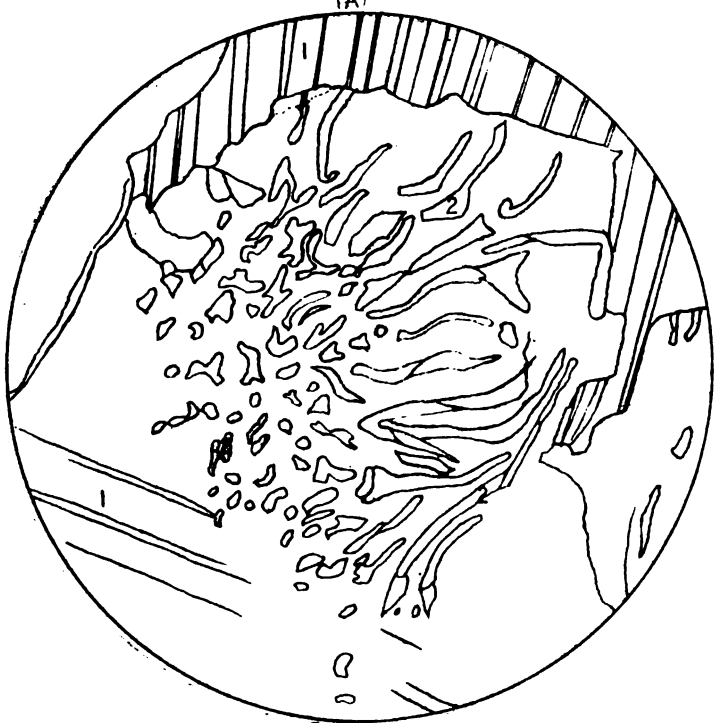
(1) Plagioclastic feldspar of low extinction; (2) canals filled with quartz in vermicular arrangement within the feldspar.

Specimen 5396, slide 2288, $\times 250$, in polarized light.

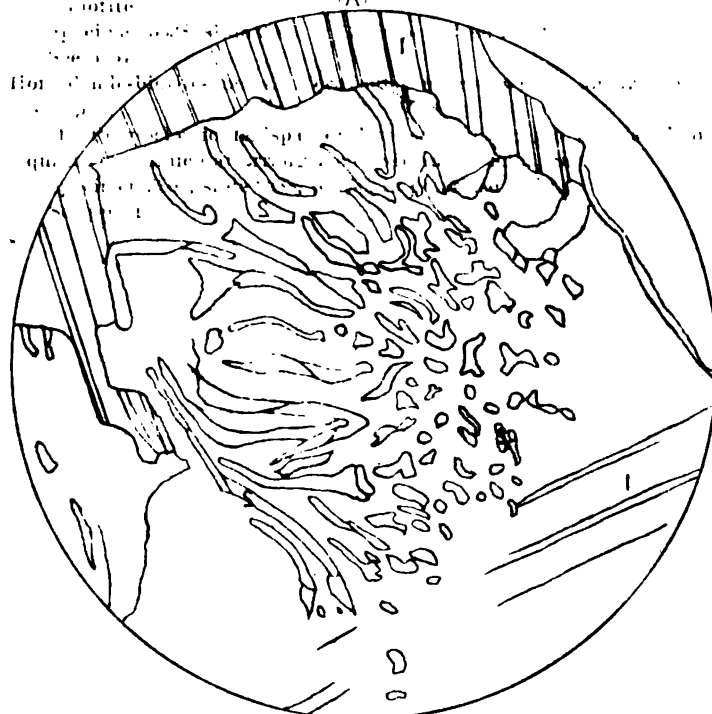
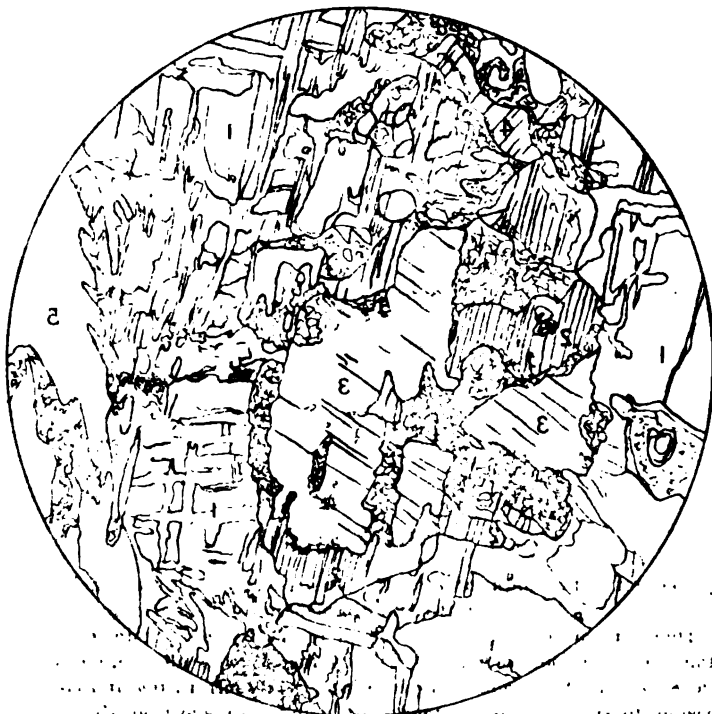
See pp. 51, 67.



(A)



(B)





(A)



(B)

(A) HORNBLLENDE - BIOTITE GNEISS (B) VERMICULAR QUARTZ

PLATE XIX.

PLATE XIX.

Fig. A. Hypersthene-free gabbro-schist. Area of diallage in which alteration to hornblende is begun. Some areas of hornblende can be seen with a low power, but many more can be recognized under higher magnification, while a green color shows that incipient alteration pervades the entire field of diallage.

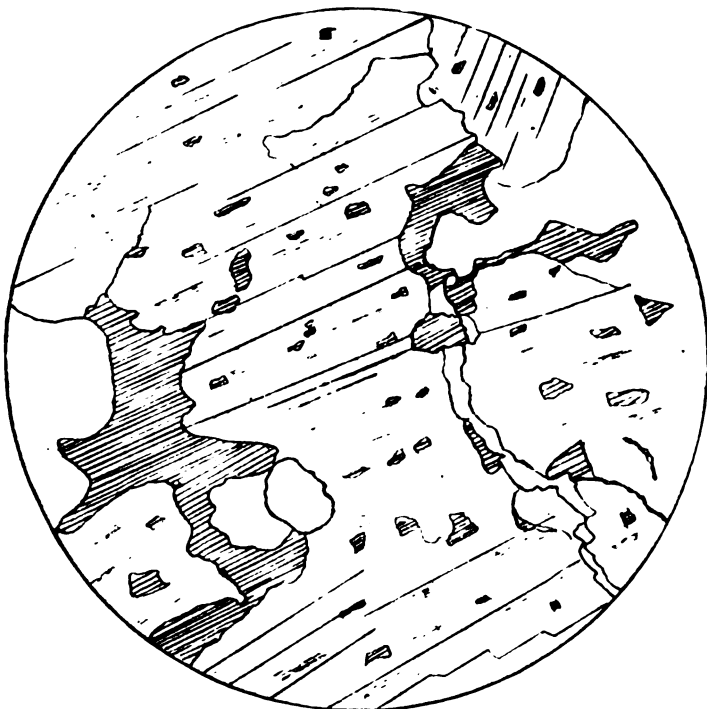
Specimen 5185, slide 1765, $\times 100$.

See pp. 80, 99.

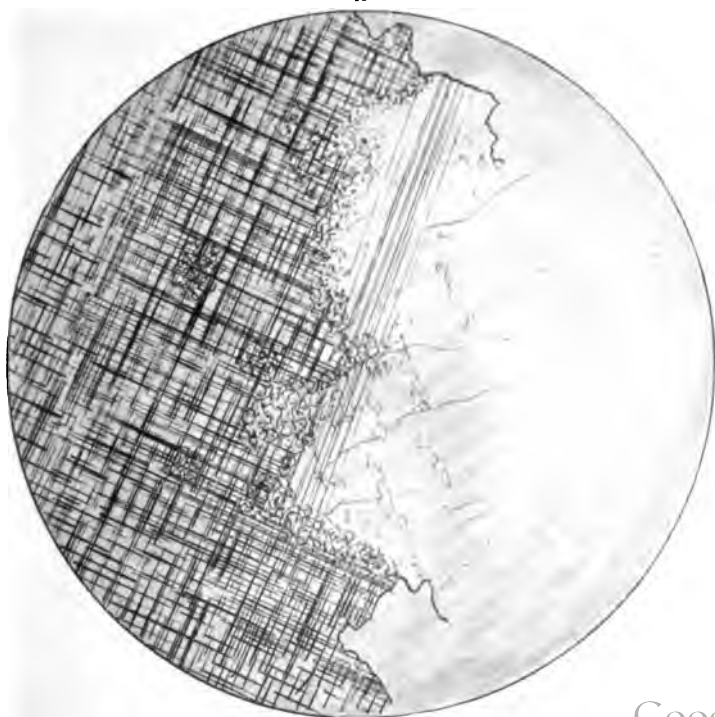
Fig. B. Hornblende-biotite granite-gneiss. Contact zone between microcline and oligoclase where the boundary is not distinct. A finely granular mineral not easily identified lies between the two recognizable feldspars. That either is secondary to the other does not appear.

Specimen 5320, slide 2457, $\times 75$.

See p. 52.



A



B

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A. HORNBLENDE IN FINE GRANULES WITHIN A LARGE PLATE OF DIALLAGE.

PLATE XX.

PLATE XX.

Fig. A. Porphyritic hornblende-biotite-gneiss. Radially arranged individuals of biotite within a quartz individual partially filling a minute fissure.

Specimen 5262, slide 2442, $\times 350$.

See p. 53.

Fig. B. Hornblende-biotite-gneiss. Microcline occurring in small anhedral individuals within a field of orthoclase. All the microcline areas extinguish together, but in this case not in the same direction as the orthoclase.

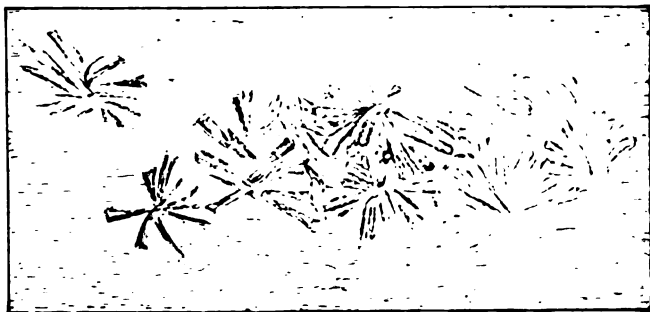
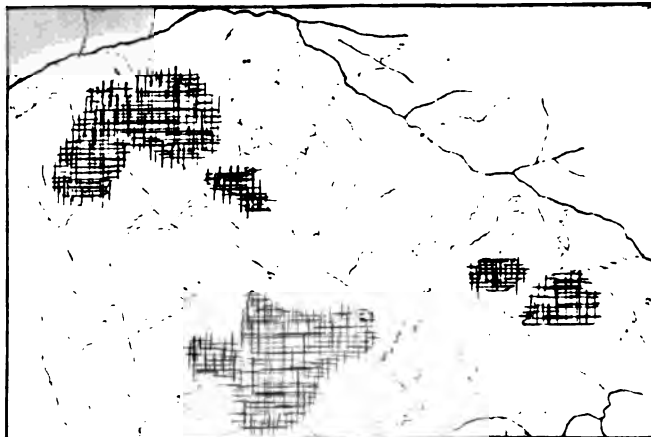
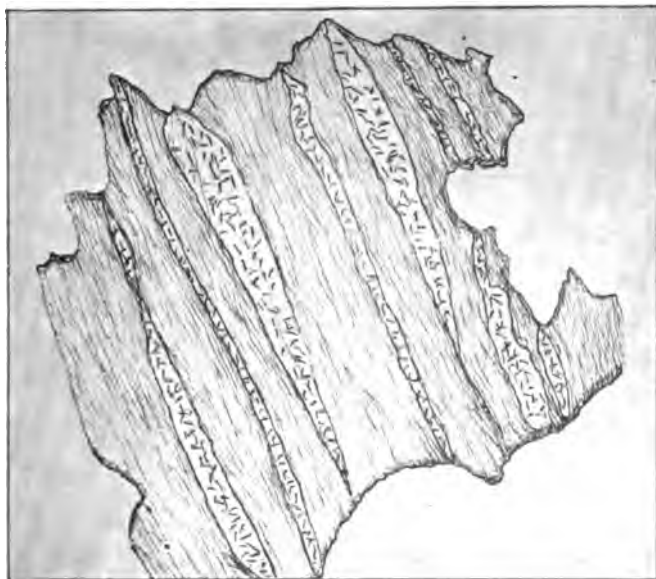
Specimen 5315, slide 2254, $\times 150$.

See pp. 52, 53.

Fig. C. Hypersthene-free gabbro-schist. Individual of biotite carrying lenses of quartz wedged in between the biotite folia. The quartz is secondary and undoubtedly the biotite is also.

Specimen 5186, slide 4432, $\times 120$.

See pp. 54, 99.

**A****B****C**

A, BIOTITE IN RADIAL CLUSTERS WITHIN QUARTZ
B, MICROCLINE WITHIN OLIGOCLASE
C, LENSES OF QUARTZ IN BIOTITE.

PLATE XXI.

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PLATE XXI.

Fig. A. Hypersthene-gabbro. There has resulted a partial alteration of the pyroxenic constituents into brown hornblende.

(1) Hypersthene, tolerably fresh in the centers of the fragments into which it has been fractured; (2) hornblende, apparently resulting from the decomposition of the hypersthene: it appears also as a filling in all the fractures within the hypersthene individuals; (3) labradorite; (4) augite.

Specimen 5278, slide 2257, $\times 48$.

See pp. 86, 91.

Fig. B. Gabbro-diorite. The pyroxenic constituents are completely altered to green hornblende.

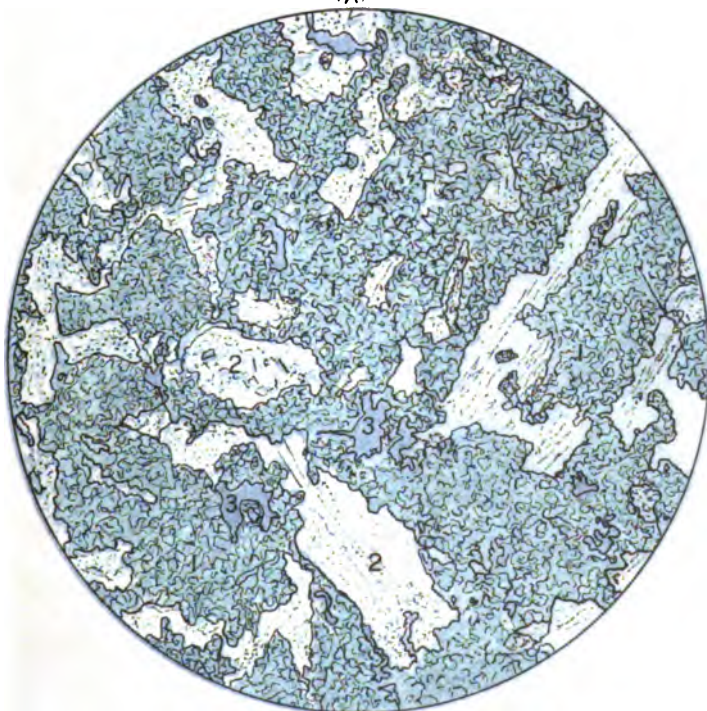
(1) Hornblende, derived undoubtedly from the decomposition of pyroxenic constituents; (2) feldspar of the anorthite-labradorite type; (3) small grains of magnetite.

Specimen 5418, slide 4442, slightly magnified.

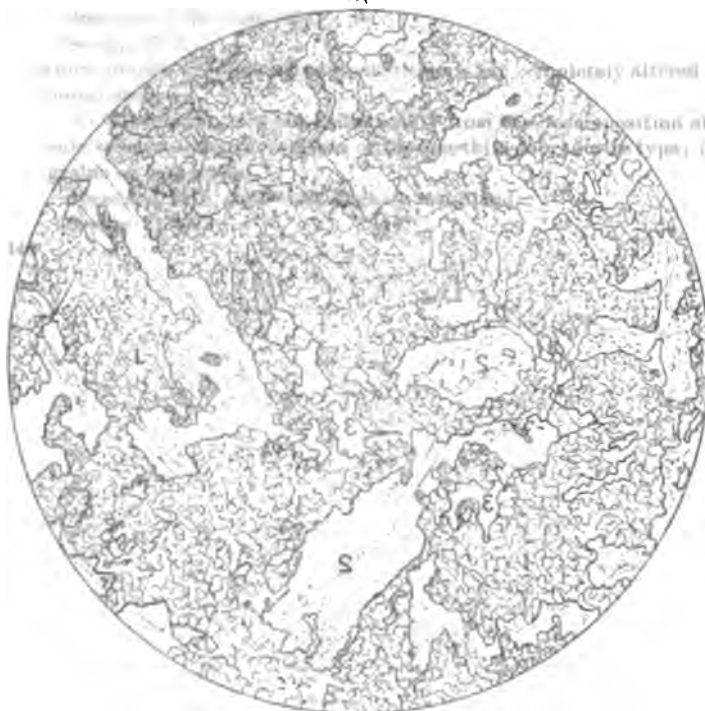
See pp. 91, 107.

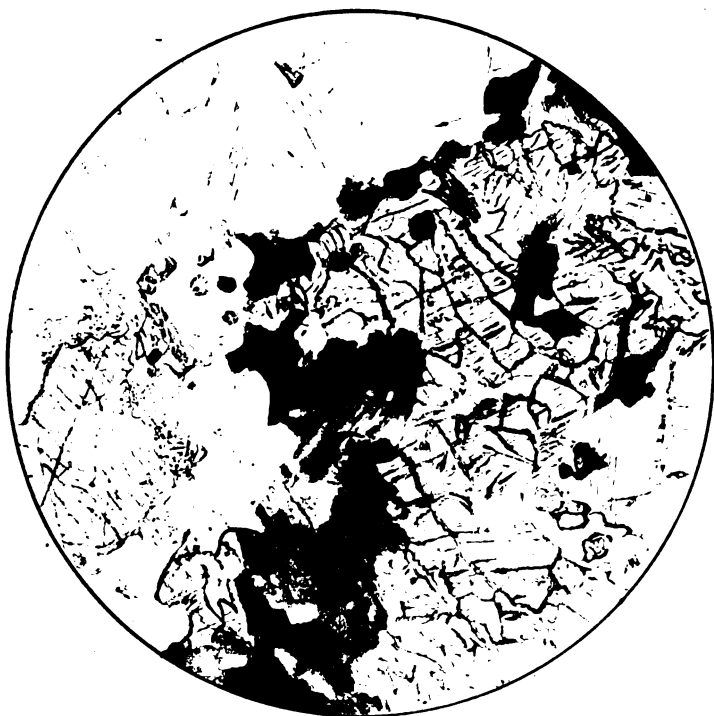


(A)

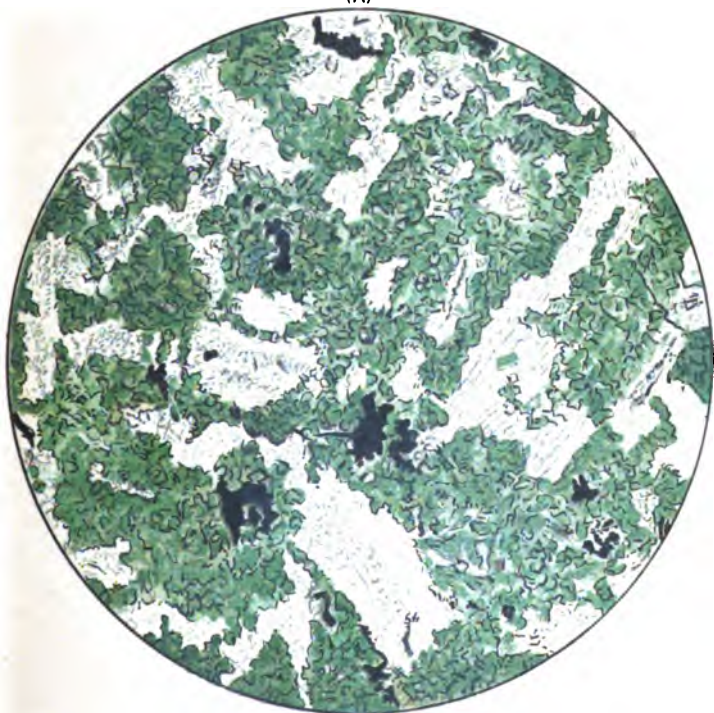


(B)





(A)



(B)

(A) HYPERSTHENE GABBRO (B) GABBRO DIORITE

PLATE XXII.

Bull. 157—10

145

PLATE XXII.

Fig. A. A gabbro in which the monoclinic pyroxenes have been almost entirely altered to a granular hornblende-biotite and quartz.

(1) Anorthite-labradorite feldspar; (2) remains of pyroxenic cores; (3) hornblende of the uralitic type; (4) biotite arranged in more or less radiating folia; (5) grains of secondary quartz.

Specimen 5279, slide 2444, $\times 100$.

See p. 105.

Fig. B. Garnetiferous gabbro in typical development at the "gold mine" just south of Granite Falls.

This gabbro is in Educational Series of Rock Specimens, United States Geological Survey, No. 109.

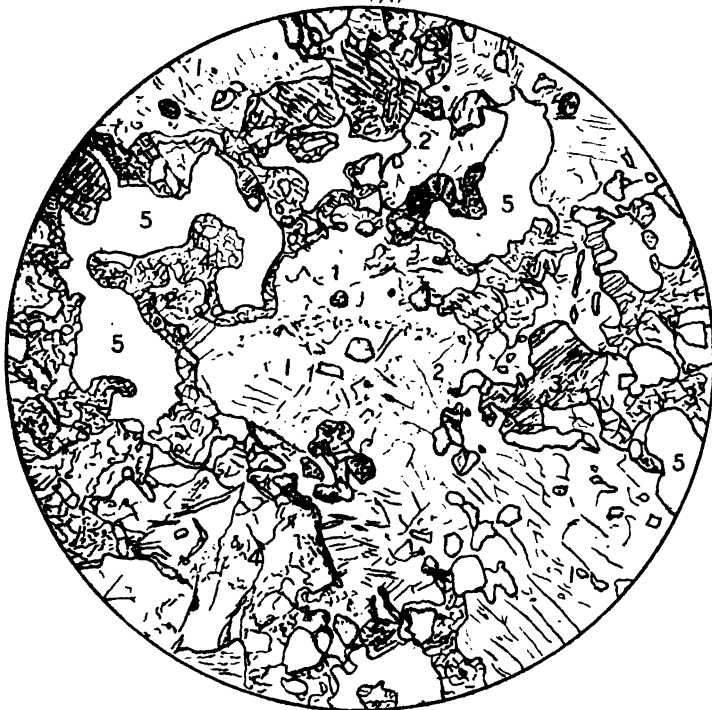
(1) Anorthite-labradorite feldspar; (2) secondary quartz; (3) diallage; (4) garnets; (5) magnetite.

Specimen 5421, slide 4444, $\times 25$.

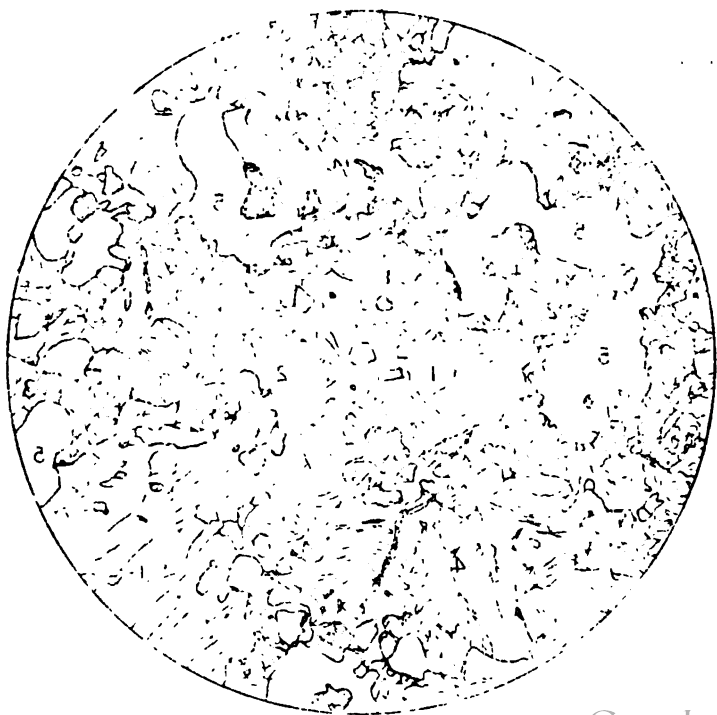
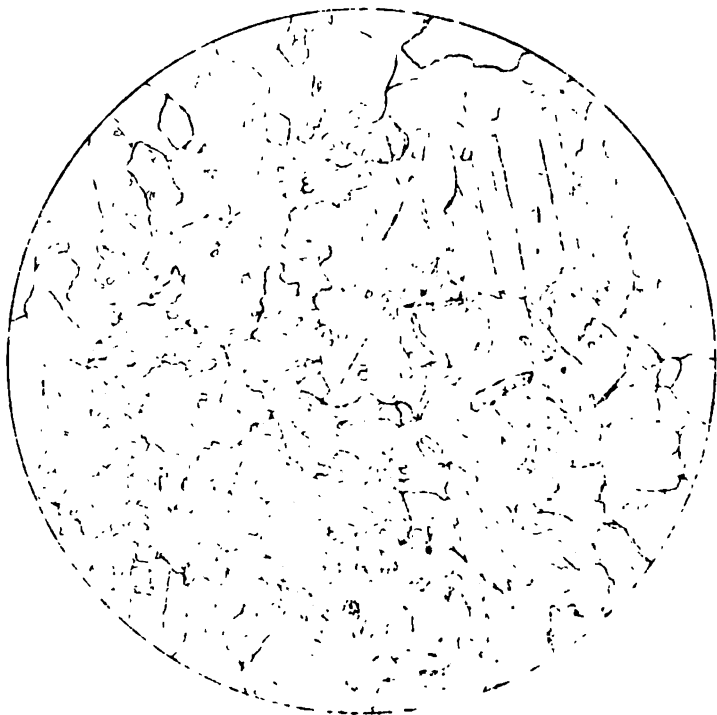
See pp. 99, 102.

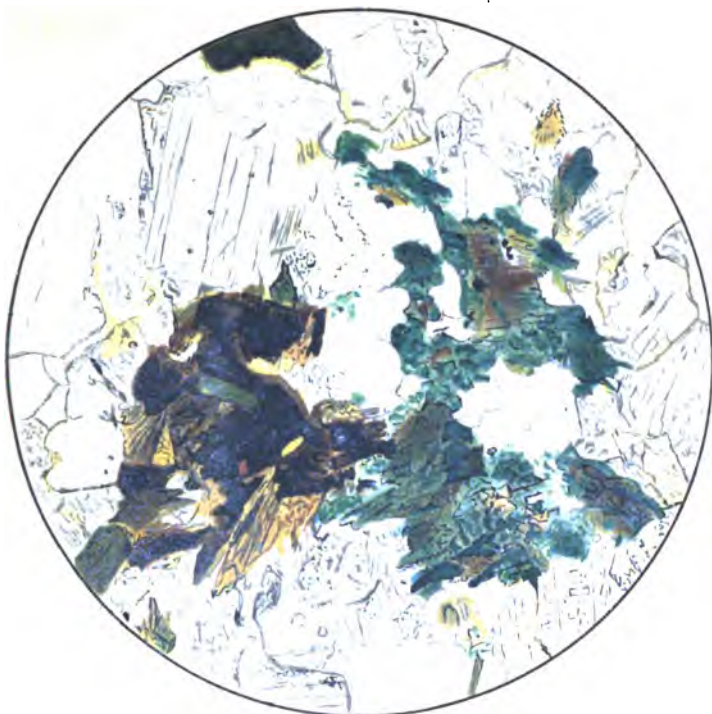


(A)

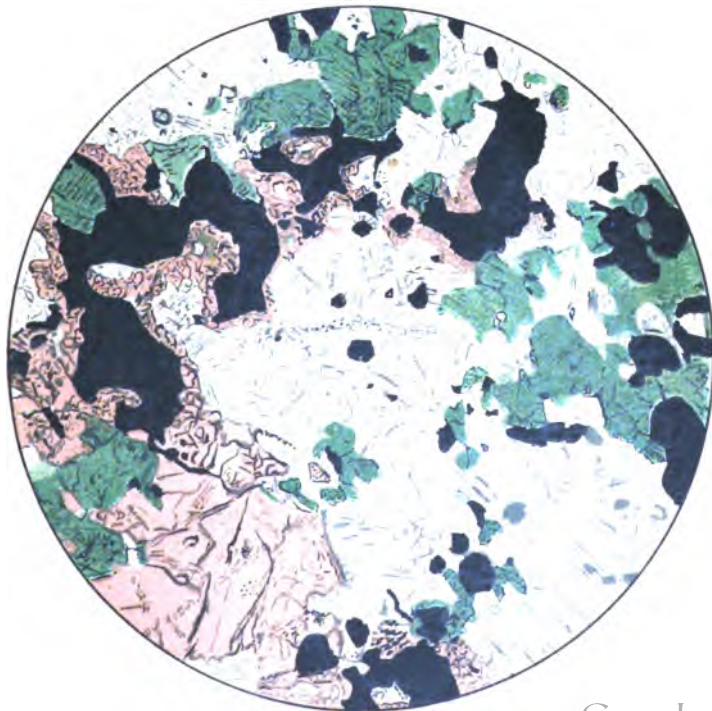


(B)





(A)



(B)

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JULIUS BIEN & CO. N.Y.

(A) ALTERED GABBRO

(B) GARNETIFEROUS GABBRO

PLATE XXIII.

PLATE XXIII.

Fig. A. Altered hypersthene-bearing gabbro-schist. A cluster of minute veins, chiefly of hornblende, occupying intergranular spaces between the individuals of plagioclastic feldspar, and even filling the spaces of fractures pushed open. Vein contents very finely granular.

Specimen 5399, slide 2289, $\times 150$.

See p. 85.

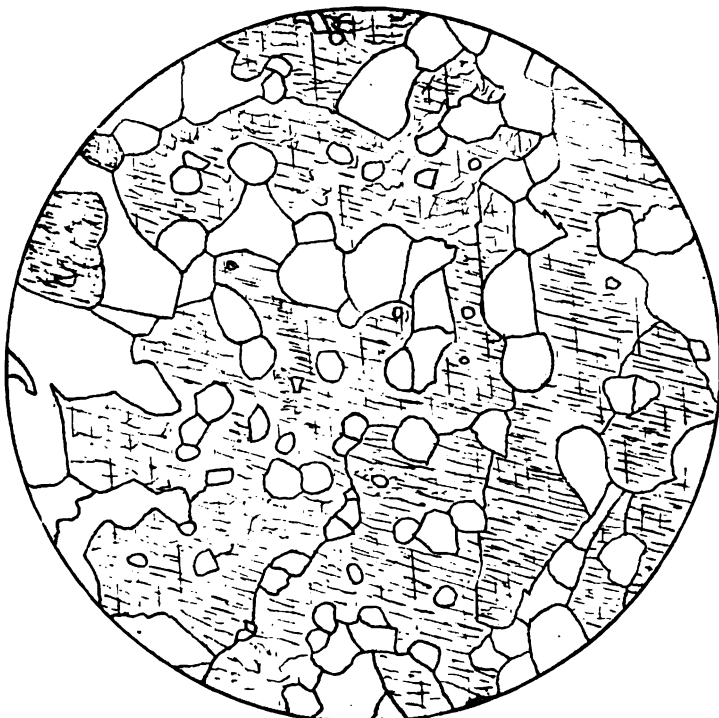
Fig. B. Hypersthene-free gabbro-schist. Diallage developed locally in large individuals containing within them the other mineral constituents of the rock. An example of poikilitic texture.

Specimen 5199, slide 1775, $\times 75$.

See p. 98.



A



B

A, ANASTOMOSING OF VEINS OF HORNBLENDIC MATERIAL BETWEEN FELDSPARS.
B, DIALLAGES AS A MATRIX CONTAINING THE OTHER MINERAL CONSTITUENTS
AS INCLUSIONS

PLATE XXIV.

PLATE XXIV.

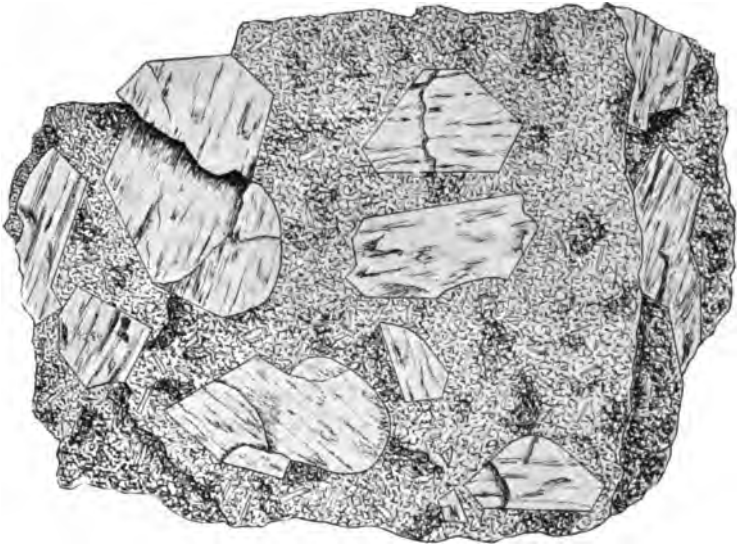
Fig. A. Porphyritic gabbro-schist. Hand specimen. The usual constituents, labradorite-anorthite, hornblende, augite, diallage, hypersthene, with accessories, lie in the groundmass, within which are developed the large and well-defined anorthite crystals.

Specimen 5438, natural size.

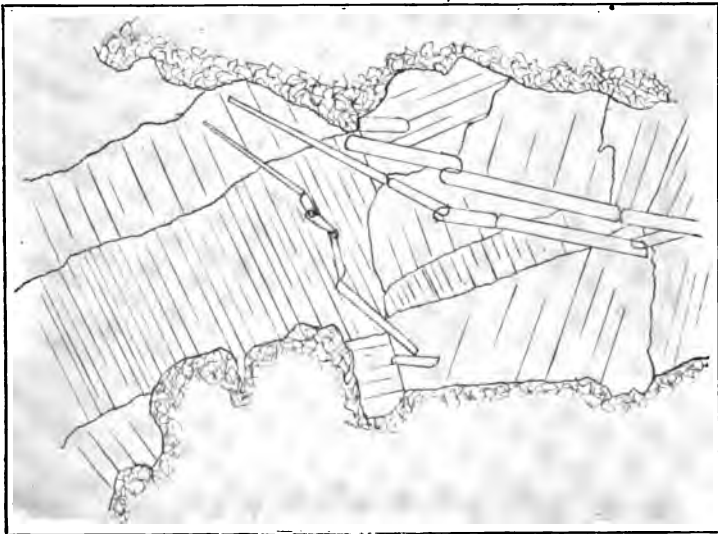
See pp. 87-89.

Fig. B. Porphyritic diorite. Fresh transparent labradorite grains, in which are seen broken apatite crystals so displaced that the fragments are shoved until they overlap one another.

Specimen 5441, slide 9470, $\times 250$.



A



B

A. HAND SPECIMEN OF PORPHYRITIC GABBRO, WEST PART OF GRANITE FALLS.
B. BROKEN APATITE NEEDLES IN LABRADORITE FELDSPARS.

PLATE XXV.

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PLATE XXV.

Fig. A. A typical diabase of the Minnesota River Valley of the normal granitic structure.

(1) Augite, with the borders altered into finely granular hornblende; (2) hornblende, in the upper left-hand corner the augite has completely altered into such hornblende; (3) broad and polysynthetically twinned labradorite-anorthite feldspars; (4) magnetite.

Specimen 5303, slide 4440, $\times 53$.

See p. 126.

Fig. B. Typical ophitic diabase.

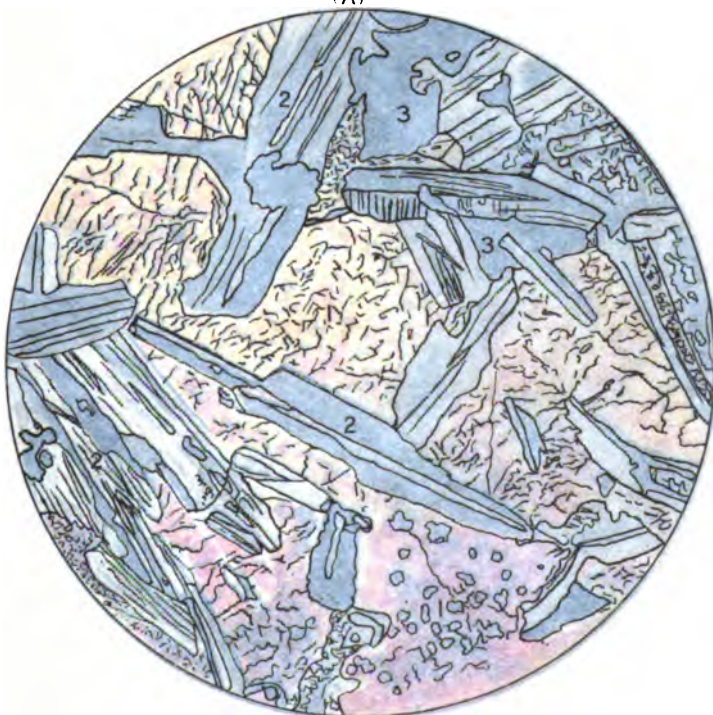
(1) Augite extinguishing simultaneously throughout the entire field; (2) labradorite-anorthite of the lathlike type, often included within the matrix of the augite; (3) magnetite.

Specimen 5286, slide 2241, $\times 70$.

See p. 123.



(A)



(B)



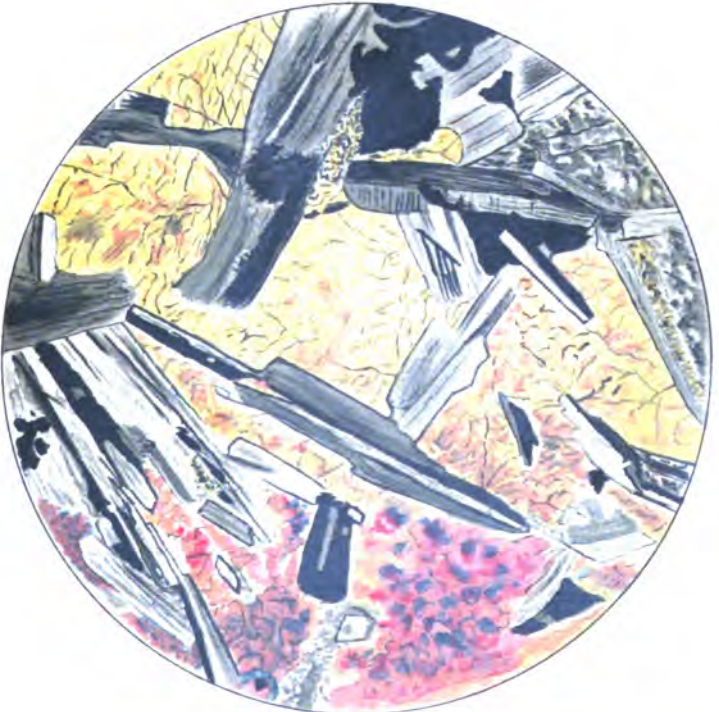
A



(B)



(A)



(B)

(A) NON-OPHITIC DIABASE

(B) OPHITIC DIABASE.

PLATE XXVI.

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PLATE XXVI.

Fig. A. Contact of finely granular diabase dike and hypersthene-free gabbro. The dike is of considerable width and of medium texture away from its contact zones, while near the contact it is porphyritic with labradorite-feldspar individuals. Among the contact minerals occur many clear minute grains of quartz.

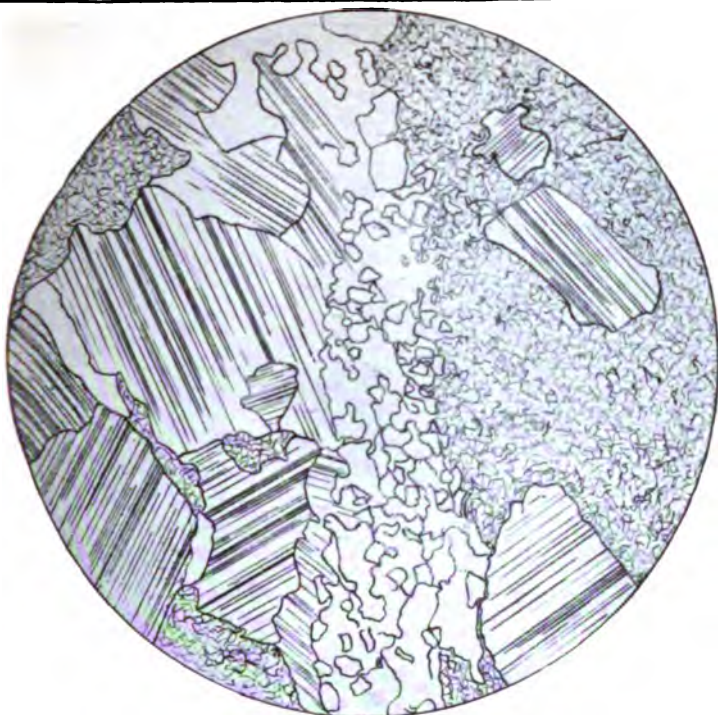
Specimen 5294, slide 862, $\times 120$.

See pp. 117, 125.

Fig. B. Areas of secondary quartz extinguishing simultaneously within a corroded feldspar. The original identity of the feldspar is obliterated. The quartz is very transparent and free from inclusions.

Specimen 5400, slide 2477, $\times 150$.

See pp. 51, 122, 120.



A



B

A, CONTACT OF FINELY GRANULAR DIKE AND HYPERSTHENE-FREE GABBRO.
B, AREAS OF QUARTZ EXTINGUISHING SIMULTANEOUSLY WITHIN A CORRODED

PLATE XXVII.

PLATE XXVII.

Fig. A. Peridotite, var. saxonite, showing enstatite and olivine, with the alteration products chiefly from olivine.

The light-brown portion (1) is a single individual of enstatite, in which the arrow marks the position of extinction. The enstatite individual is considerably shattered, and the fractures diverge as though they resulted from the hydration of the partially altered olivine. Such fracturing seen in certain forellensteins (troctolites) is attributed to that cause. The single olivine individual (2) shown in the central portion of the figure is at least one-half altered into serpentine and magnetite. The alteration has proceeded from the fractures, and the largest olivine areas occur where these fractures were least frequent. The serpentine (3) lies in strings and bands between the fresh olivine remnants.

Specimen 5216, slide 1785, $\times 180$.

See p. 112.

Fig. B. Serpentine derived from the alteration of saxonite. A portion of the serpentine has been further replaced by quartz. Sec. 9, T. 112 N., R. 34 W.

Specimen 5216, slide 2221, $\times 180$.

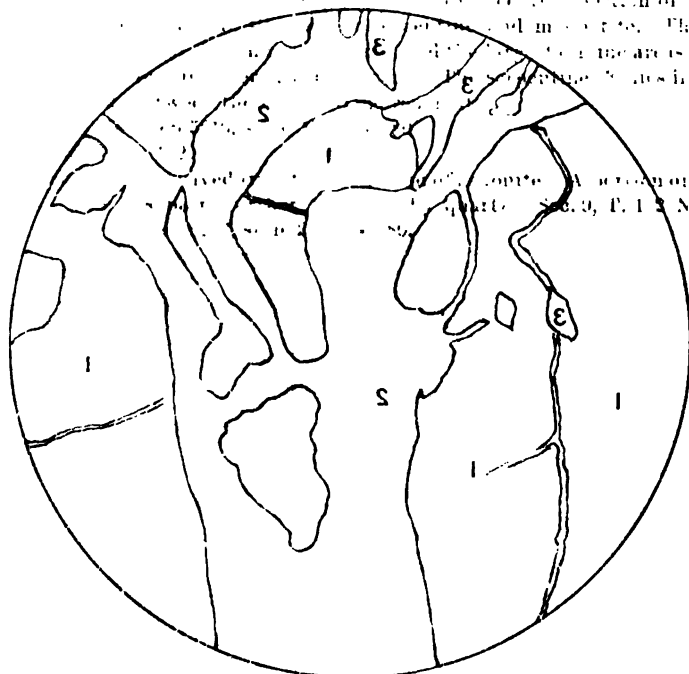
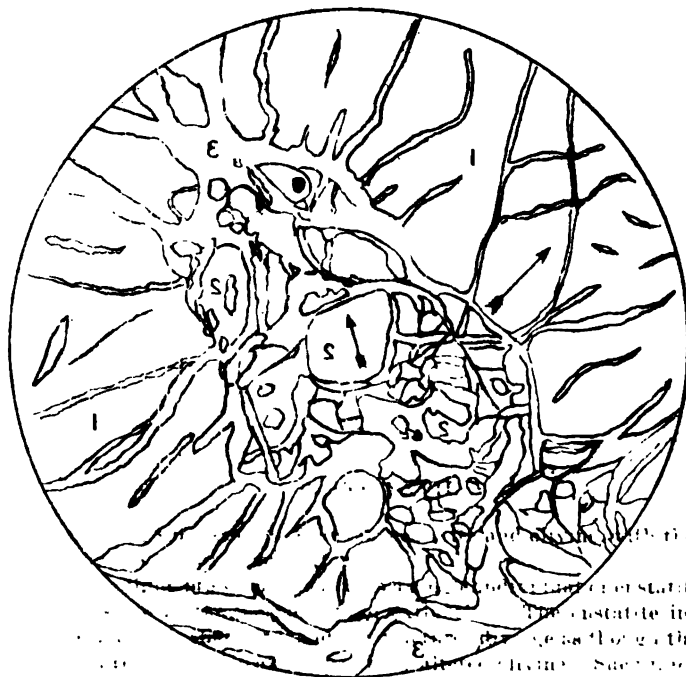
See p. 114.



(A)



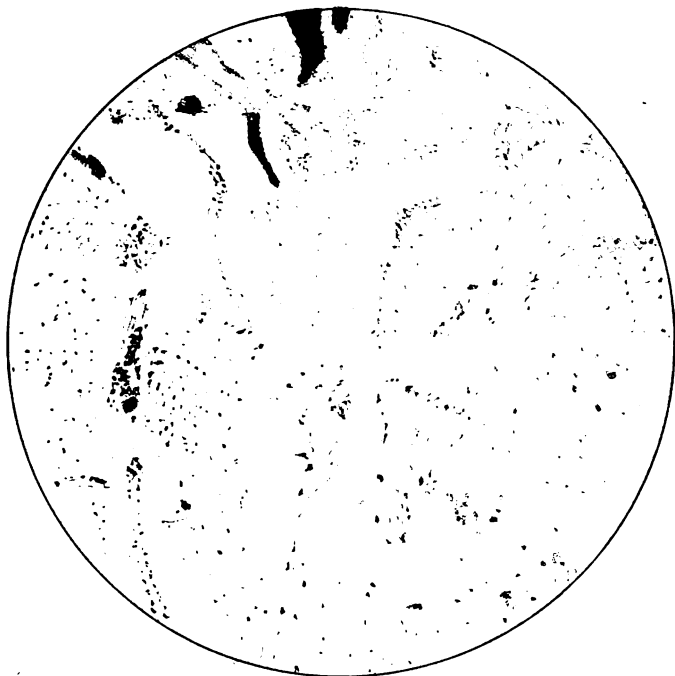
(B)



(E)



(A)



(B)

(A) ALTERED PERIDOTITE (B) SERPENTINE

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DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 158



WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

THE
MORAINES OF SOUTHEASTERN SOUTH DAKOTA

AND

THEIR ATTENDANT DEPOSITS

BY

JAMES EDWARD TODD



WASHINGTON
GOVERNMENT PRINTING OFFICE

1899

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Chicago, Ill., August 22, 1898.

SIR: I have the honor to submit herewith a report by Prof. James E. Todd on The Moraines of Southeastern South Dakota and their Attendant Deposits, which will be found to contain a large amount of valuable data relating to the later formations of that State.

Very respectfully, yours,

T. O. CHAMBERLIN,
Geologist.

Hon. CHARLES D. WALCOTT,
Director of the United States Geological Survey.

THE MORAINES OF SOUTHEASTERN SOUTH DAKOTA AND THEIR ATTENDANT DEPOSITS.

By J. E. TODD

CHAPTER I.

INTRODUCTION.

HISTORY OF WORK.

At the reorganization of the United States Geological Survey in 1881, the author, under the direction of Prof. T. C. Chamberlin, geologist in charge of the glacial division, was instructed to explore the Dakota loop of the great moraine. At that time very little was known of the distribution of drift in Dakota. Aside from certain theoretical considerations which had been expressed by Professor Chamberlin and Mr. Warren Upham, little had been presented upon the subject. A few topographical notes by Nicollet in 1842, and a more direct treatment of the subject from wide but incomplete observation, presented by Gen. G. K. Warren in 1868 before the Chicago meeting of the American Association for the Advancement of Science, were the more important statements of observation. The latter distinctly makes the limit of glacial action to coincide with the Missouri River from the forty-eighth to the forty-third parallel. Dr. F. V. Hayden also, in the American Journal of Science for January, 1867, published a very interesting account of a trip taken by him to Rockport, Dakota, and Pipestone, Minnesota, in the previous October. His notes refer mainly to the older formations, but incidentally he records features of the drift.

After an examination of the field during the summers of 1881, 1882, and 1883 it was considered better to delay a report upon the whole region, and to present a preliminary report in the form of a bulletin upon a limited portion. The portion chosen, and to which this bulletin relates, was thought to bear most directly upon certain important questions and to be likely to furnish the most important results; moreover, it was the most accessible portion, because more generally occupied by settlers.

LIMITS OF REGION.

The limits chosen in the regular course of the moraine—the axial limits—are Turtle Point in Jerauld County, and a corresponding point in the northwestern part of Lake County. For convenience in reference we will name the latter Vermilion Point. Turtle Point is a conspicuous landmark, which forms a natural point of division on the west side of the loop, while Vermilion Point is on the east side of the loop in about the same latitude, and, although it is not so prominent a point of division, it is the most marked point near the northern limit of the writer's acquaintance with the moraine upon the east side. Turtle Point is upon the eastern edge of what is commonly known as the Coteau du Missouri, a region between the James and Missouri rivers spoken of by the early French explorers as the Plateau du Coteau du Missouri. The term "plateau," however, is a misnomer, for instead of a continuous plateau, it is merely the skeleton of one. The peripheral limits are, briefly, as follows: On the north, the parallel of Turtle Point, which is arbitrarily taken. On the other sides the limit theoretically coincides with that of the extreme dispersion of erratics from the portion of the moraine under consideration. On the west this boundary is most definite and is near; on the east it is confused with that of the Iowa lobe; on the south the theoretical limit is so remote that we shall need to fix an arbitrary limit, which we will take as not more than 100 miles from the moraine. A map of the region under consideration is shown on Pl. I.

Some of the advantages which may be derived from a careful presentation of this portion of the moraine are the following:

First. It gives opportunity to present in a natural and consecutive manner several typical features of drift deposits, moraines, berg drift, drainage outlets, gravel terraces, osars, etc.

Second. It furnishes important data upon several of the open questions connected with certain Pleistocene problems, viz: The origin of loess, the distribution of glacial and glacio-natant deposits, oscillations of the earth's crust in the post-Pliocene, besides several minor questions connected with the physics and history of the glaciers.

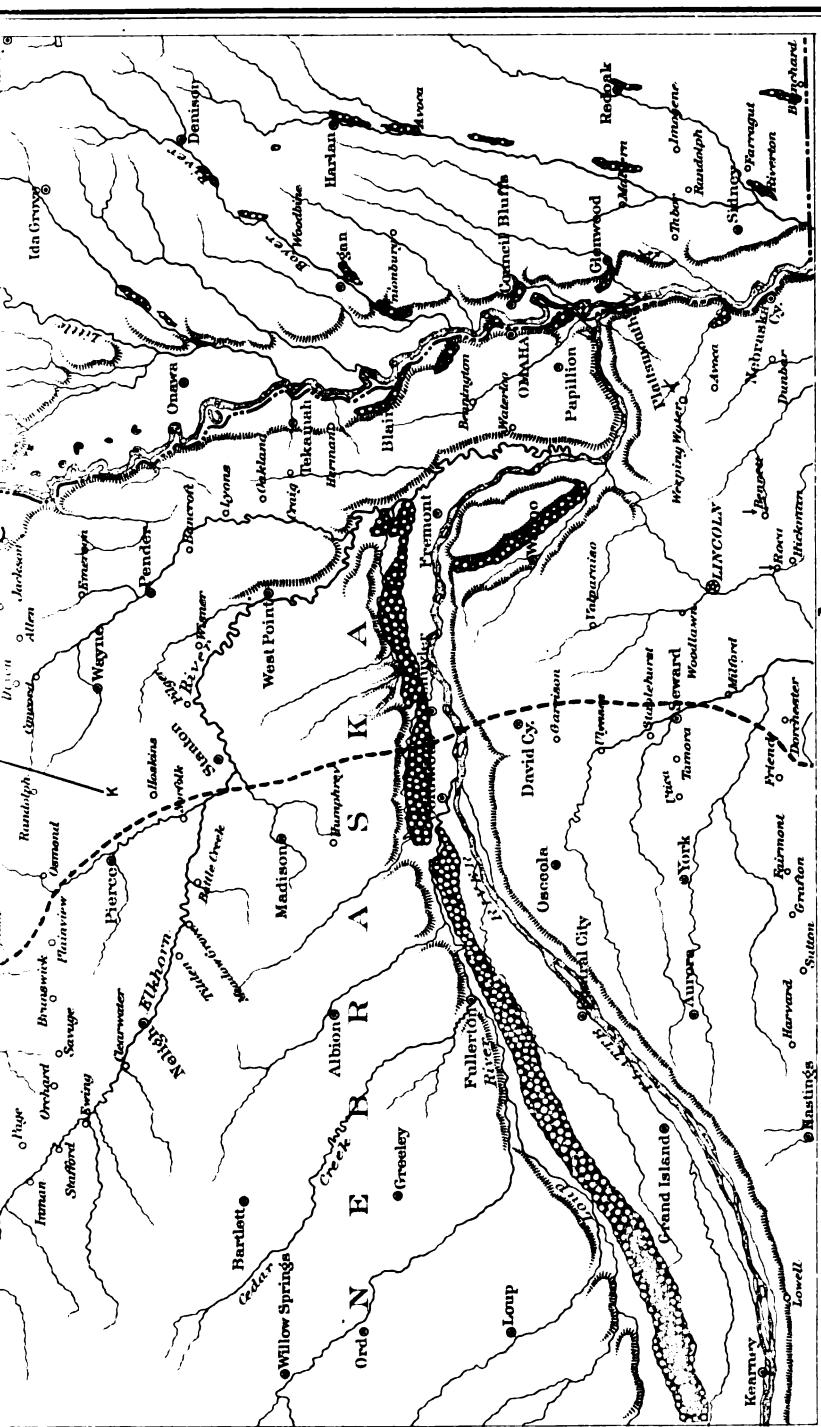
Third. It forms a convenient introduction to the larger subject which it was first proposed to present.

SKETCH OF OLDER FORMATIONS.

Though our work pertains especially to the recent deposits formed during the Pleistocene period, a brief consideration of older deposits seems important, for the underlying rocks have influenced in several ways the distribution of the drift.

The older formations belong to widely separated epochs. So far as is yet known, the region under consideration exhibits only strata belonging to the Algonkian and the Cretaceous, with scattered fragments of





A. H. M. & Co. Lith. Baltimore.

Note: Numbers on this map denote comparative age of moraines

PLEISTOCENE DEPOSITS OF SOUTHEASTERN DAKOTA AND ADJACENT REGIONS

BY J. E. TODD, 1898

X STRIÆ. ■ MORAINES. ■ TERRACES AND OLD CHANNELS. --- LIMIT OF NORTHERN OR GLACIAL DRIFT.

Tertiary deposits. The Algonkian—or, as it has been considered by Prof. N. H. Winchell, the lower Cambrian—is represented only by the red quartzite, which is conspicuously exposed along the Big Sioux, and was named several years since by Dr. C. A. White the Sioux quartzite. The exposures in this region appear to be portions of an irregular syncline, extending from southwestern Minnesota to the James River. An enumeration of localities will be found on another page (p. 122). The strata have usually but slight dip, rarely more than 6°. Ripple marks are frequent, but no fossils, except a few of doubtful character, have yet been found.¹ The rock bears evidence of ebb-and-flow structure. Oblique stratification, inclining in different directions, abounds in some strata. Thin seams of metamorphosed clay occur occasionally, the more notable being the “pipestone,” at Pipestone, Minnesota. The lower stratum exposed on Wolf Creek is a bed of unconsolidated sand, evidently once consolidated but now decomposed.

The Cretaceous rocks all belong to the Dakota group and to the three members separated by Hayden, but combined by King into the Colorado group.

The first, the Dakota sandstone, is exposed along the James River and its tributaries in Hutchinson, Hanson, and Davison counties and along the Missouri below Ponca, Nebraska.

The Benton group, comprising dark pyritiferous clays, is certainly found exposed only along the bluffs of the Missouri, from near the mouth of the James River to the vicinity of the Big Sioux.² Slight exposures near Milford, Nebraska, and Rockport, Dakota, also possibly belong to this group.

The Niobrara of Hayden, the chalkstone, forms a more conspicuous and important deposit, which extends very widely under the drift. It is exposed along the Missouri from Chamberlain to St. Helena; along the James and its tributaries in Hanson and Davison counties; at several localities along Clay and Turkey creeks; upon Beaver Creek, near Canton; on the Split Rock, north of Brandon; along the Big Sioux, at Akron and below, comprising the *Inoceramus* beds of White, and along Brule Creek, in Union County.

The Pierre group, consisting of clays of different colors and qualities, probably occupies four-fifths of the surface underneath the drift. It is exposed along the Missouri from near the mouth of the Niobrara to the northern limits of the region. It is this formation which is struck in wells which pass through the drift in all localities in the Dakotas east of the Missouri, except those that have been already indicated.

The Tertiary rocks are represented by the greenish quartzite—well shown at the Bijou Hills—and various beds of sand, gravel, and clay that are associated with it. These are ascribed to the Loup River group by Dr. Hayden, and no reason for questioning the determination

¹ Prof. N. H. Winchell, Thirteenth Ann. Rept. Geol. Nat. Hist. Survey Minnesota, 1884.

² Cf. Hayden, 1870, p. 87.

has come to the writer's knowledge.¹ Distinct fossils were not noticed by him in it, though pieces of petrified wood and of mammalian bones have been noticed upon it, which may have been derived from it. It contains greenish pebbles of pitchstone at many points. In northeastern Nebraska the Loup River Tertiary is represented by over 80 feet of sands, marls, and clays containing petrified shells and bones of animals. From similarly situated beds north of Sioux City teeth of *Equus major* have been reported by Mr. Bain, who referred the beds to the Pleistocene.²

The Oretaceous clays have contributed largely to the mass of the till. The Tertiary rocks have been influential in the formation of buttes which have had an important limiting and directing influence upon the ice sheet. The Archean rocks have been less influential, not having been prominent enough to limit or deflect the ice, nor sufficiently yielding to contribute material of much volume. In a few cases, as at Rockport and near Alexandria, they seem to have exercised considerable directing power upon the lower portion of the ice.

ELEVATIONS.

The elevations which form an important portion of this paper were mostly taken with an aneroid barometer. A few are derived directly from railroad profiles. The more important elevations have been taken either several times or on days when the barometer showed little fluctuation. In general their accuracy corresponds to their distance from important streams or from railroads. A few are taken from the topographic surveys of the United States Geological Survey. At the beginning of our work the number of railroad elevations in the region under consideration was quite small, on account of its recent settlement. But the rapid railroad building of the last few years has been favorable to the work, both by furnishing exposures and in affording fresh and accurate information concerning elevations. The accuracy of the survey has been materially aided through the generous response on the part of railroad engineers to requests for profiles. In the appendix several of these are published for the first time.

ACKNOWLEDGMENTS.

I would hereby gratefully acknowledge my indebtedness to Mr. D. J. Whittemore, chief engineer of the Chicago, Milwaukee, and St. Paul Railway Company, for a carefully prepared list of elevations of all stations and bridges over important streams along its lines in the States of North and South Dakota; to Mr. E. Gerber, assistant engineer of the Fremont, Elkhorn and Missouri Valley Railroad Company, for elevations upon all its lines in Nebraska, a section of the Missouri River at Blair, and other favors; to Mr. C. W. Johnson, chief engineer

¹ Gen. G. K. Warren's preliminary report on Nebraska and Dakota, p. 78.

² Iowa Geol. Survey, Vol. V, p. 277.

of the Chicago, St. Paul, Minneapolis and Omaha Railway Company, for elevations of all stations on its lines in Nebraska, and a section of the Missouri at Sioux City; to Mr. B. B. Colborne for a profile of a preliminary survey from Chamberlain, Dakota, to Lemars, Iowa; to Mr. George A. Lederle for a section of the Missouri at Omaha; and to Mr. J. H. Charles, of Sioux City, for obtaining elevations on the Sioux City and Northern Railway and the Pacific Short Line. I would also express gratitude to Hon. Alexander Mitchell, of the Chicago, Milwaukee and St. Paul Railway Company, and to Hon. Marvin Hughitt, general manager of the Chicago and Northwestern Railway Company, for favors shown in transportation.

Bull. 158—2

CHAPTER II.

FIRST (OUTER) OR ALTAMONT MORAINE.

This is first presented because it furnishes a convenient line of reference in the further treatment of the area under consideration. It is also the best defined and most constant feature.

COURSE OF THE MORAINE.

The accompanying map, Pl. I, with a brief explanation, will give a comprehensive view of the direction and divisions of the moraine.

Beginning at Turtle Point, in Jerauld County, the head of a prominent interlobular portion, the moraine extends in a south and southwest direction past the Bijou Hills, nearly to the junction of Pratt Creek with the Missouri, where there is a gap a few miles in breadth. The more notable variation from a direct course is a small loop pushed westward toward Red Lake.

East of Pratt Creek the moraine appears again in the Cedar Creek Hills, which, lying on both sides of Cedar Creek, form a high V-shaped reentrant angle, pointing northeast. From the eastern end of the V the moraine extends in a general southeasterly direction, nearly to the junction of Wet Choteau and Dry Choteau creeks, where it crosses the former, turns sharply northward, and forms a long interlobular portion around the latter stream, being known as the Choteau Creek Hills. Below the junction of the Choteaus the moraine lies along the west bank of the stream nearly to its mouth, where it crosses and continues close along the bluffs of the Missouri to a point opposite the mouth of the Niobrara, where it develops a slight reentrant angle.

From this point no trace of it is found on either side of the Missouri until we pass below Bonhomme. A little east of that place, on the north side of the Missouri, it appears again, and, after forming a long and much-eroded loop to the east, reaches Lesterville, where, after forming a much smaller similar loop, it takes a southeasterly direction. About 6 miles east of Yankton it swings more to the east, crosses the James River, and continues to a broad gap through which Clay Creek passes. East of the Clay Creek Gap it reappears along the east bank of that stream and runs north and northwest to the vicinity of Childstown, where it again doubles upon itself and takes a quite direct course southeast to Spirit Mound, 6 miles north of Vermilion, forming Turkey Ridge.

East of Spirit Mound no trace of it is found until Brule Creek is reached, 10 miles east. There it reappears, running northward to Beres-

ford, and thence north-northeast to the vicinity of Canton. From that place to the vicinity of Sioux Falls it seems not to have been formed, except at three or four isolated points. About 5 miles east-southeast of Sioux Falls it reappears on the west bank of the Big Sioux, and curves around the bend of the Big Sioux at Sioux Falls, and thence west and northwest to the vicinity of Montrose. From there it lies along the east side of the East Vermillion River to Vermillion Point, about 12 miles northwest of Madison. There it forms a reentrant angle by turning sharply to the east.

The map represents also the course of the moraine for some distance outside the limits chosen.

FROM TURTLE POINT TO PRATT CREEK.

We have found it convenient to begin at the prominent headland in Jerauld County known as Turtle Point. A view of this from the

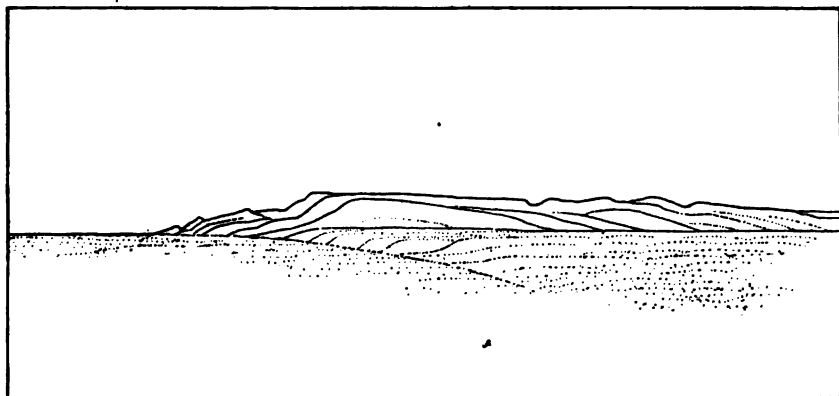


FIG. 1.—Turtle Point, from the northwest.

northwest is given in fig. 1. This forms the northern end of a high, even-topped ridge which extends from sec. 35, T. 108, R. 65, to the southern portion of T. 106, R. 65, a distance of 12 miles.

The point derives its name from the unique figure of a turtle, 1 rod in length, formed upon a mound capping the summit of the point. This figure is formed of small bowlders placed at short intervals so as to describe the outline of a turtle. The range extending south we shall call Turtle Ridge (Pl. II). Its height above the plain to the east is nearly 500 feet. Its eastern face is quite abrupt, and along its northern portion is much marked by gulches, which arise from springs issuing from beneath the drift. One of them is known as Wessington Spring, which pours forth a copious supply of slightly sulphurous water.

These gulches seem very subject to landslides, which have repeatedly changed the location of the springs. This tendency to slide is probably the effect of water softening the clays below. Some of

these springs are connected with long, trough-like ridges. One in particular, running east from an old exit of the Wessington Spring, is extraordinarily large. It extends eastward from the face of the ridge, $1\frac{1}{2}$ to 2 miles, with a height midway of from 50 to 75 feet above the adjacent slope.

The western side of the Turtle Ridge subsides with a gentle slope to a broad, undulating plain, around the heads of Smith and Crow creeks.

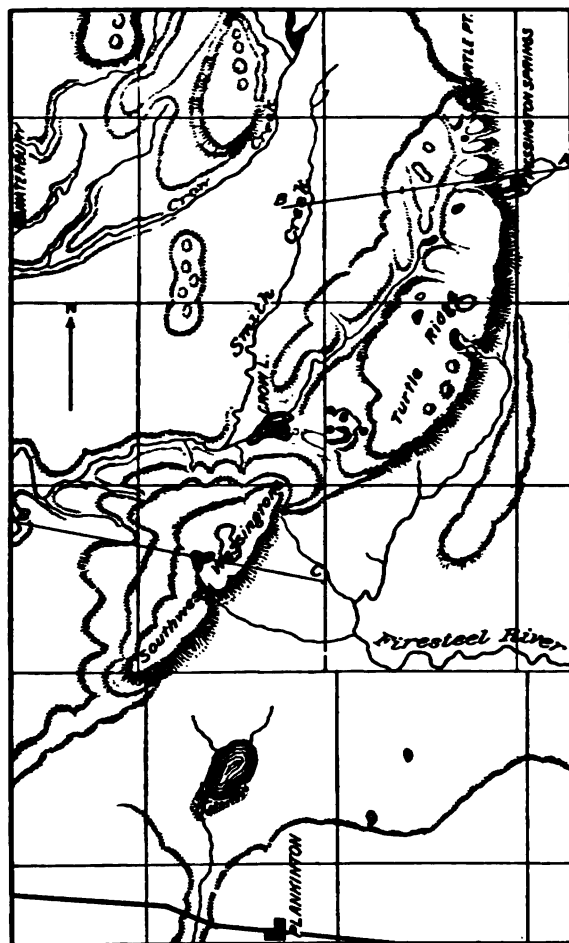
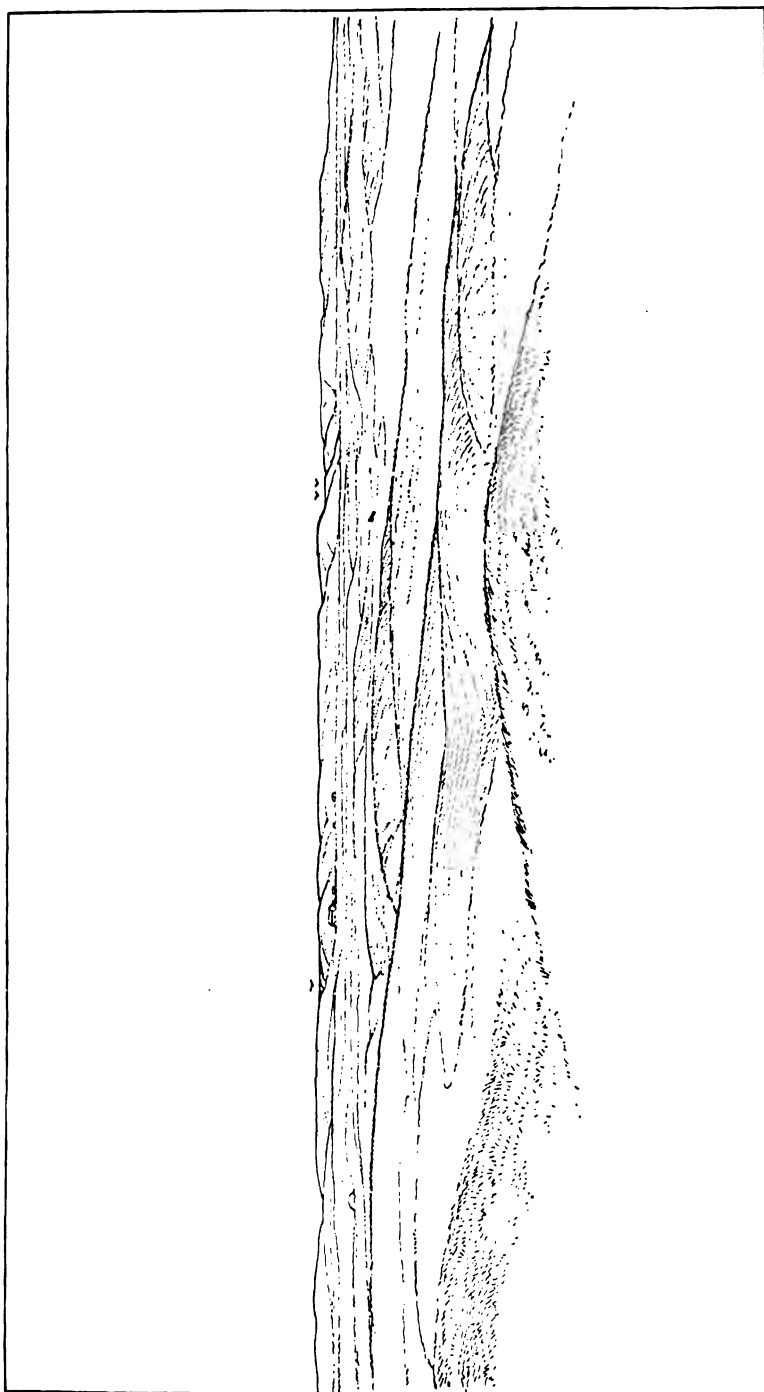


FIG. 2.—Map of Turtle Ridge and southwest Wessingtons.

This plain is considerably eroded near these streams. The top of Turtle Ridge is in several places rough and very stony, exhibiting the characters of a typical moraine. This is especially true toward its western side at the north end, and along the eastern side farther south. Among these knobs are frequent basins, some of them containing water.

A very remarkable feature in this ridge is a long, deep, narrow val-



VIEW OF TURTLE RIDGE FROM THE EAST.

v Westington Spring Gulch. vv Gulch connected with ancient channel (see fig. 2 and Pl. III).

ley, with abrupt sides, extending from near the north end through the center of the ridge 6 or 7 miles toward the south. It then turns abruptly to the southwest and flows into Crow Lake. Tributary valleys beginning at the face of the hills, on either side, form with this central valley a complete drainage system. In the main channel are a few isolated domes 25 or 30 feet in height, apparently composed of gravel and boulders. At different places in the channel are basins containing water which form considerable lakes, and are not improbably the sources of supply for the springs before mentioned. Muskrat Lake is possibly the principal supply of the Wessington Spring. Some of the ancient water channels have recently been eroded by water flowing eastward, either upon the surface or by springs cutting backward into the hills. A conspicuous example is represented in Pl. III.

The general arrangement of the drainage system is shown in the accompanying map, fig. 2.

An interesting question which may be conveniently discussed at this point is: How much of these high portions of the moraine is due to glacial action and how much to pre-Glacial topography? Turtle

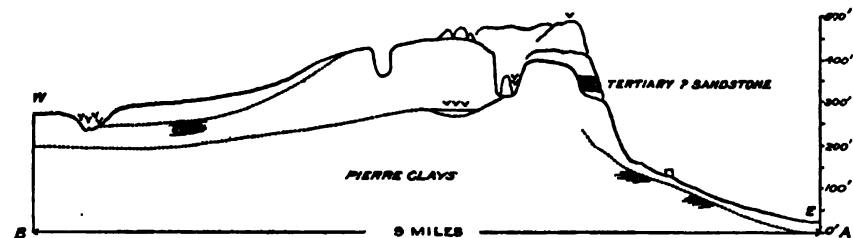


FIG. 3.—Transverse section of Turtle Ridge. v Turtle Point. vv Ancient channel leading to Crow Lake. vvv Crow Lake. vvvv Smith Creek.

Ridge affords several features which indicate that the glacial action has been the least efficient of the two—in other words, that the position and the greater portion of the mass are due to erosion antedating the glacier. As will be seen from the accompanying section fig. 3, there are exposures of sandstone in the east front of the hills in sec. 12, T. 107, R. 65. This sandstone is evidently similar to that capping the Bijou Hills and the buttes farther west. The deposit is not consolidated into a quartzite, as is usual in such localities, but shows similar structure even to the occasional occurrence of beds of grit between the finer layers.

Below the beds of sandstone are lead-colored clays, occasionally exposed in the deepest portions of the gulches. A more striking evidence of their existence is seen in the numerous landslides which have occurred near the various springs. The sulphurous ingredients of the waters are probably traceable also to the pyrites in the clays. Along the east foot of the ridge the drift is thin, and wells frequently reach the Cretaceous clay 15 to 20 feet below the surface.

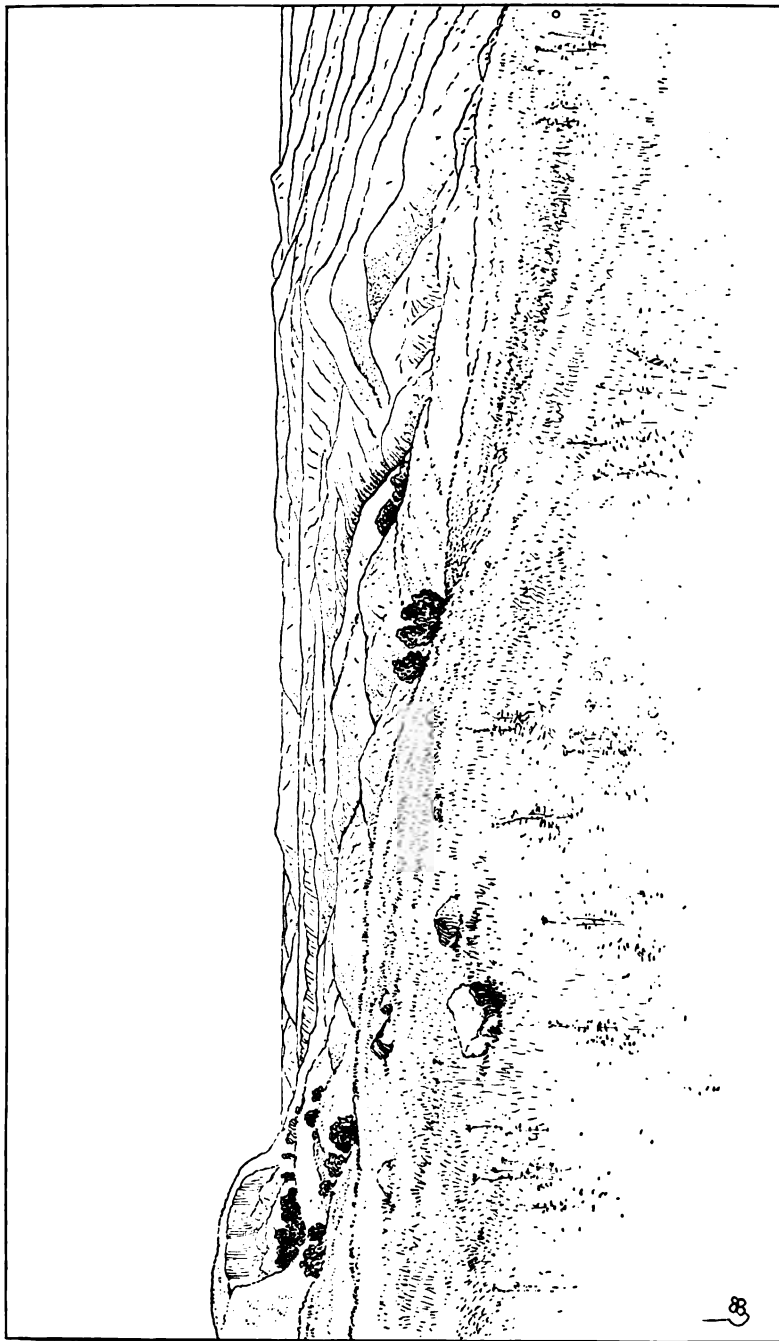
Another evidence of the influence of pre-Glacial topography is seen in the configuration of the country north of Turtle Ridge. Extending northwest is the edge of a terrace, quite distinctly marked, about 250 feet above the level of the plain on the east. This terrace is covered with drift, and its edge is seamed with gulches, which are faint imitations of those in Turtle Ridge. It also abounds in bowlders, some of considerable size. A ready explanation of this feature would be that it marks the former edge of a great valley, more commonly known as the James River Valley, and that the force of the ice sheet was sufficient to override this portion because of its lower altitude, while Turtle Ridge was able to hold its own against it.

Before proceeding further we may find illustrated in Turtle Ridge an interlobular moraine, as defined by Professor Chamberlin. It occupies the space between the shallower western lobe and the main body of the great Dakota lobe on the east. The internal drainage system already described was evidently occupied by superglacial streams which entered it from either lobe and drained through Crow Lake into the present valley of Smith Creek. That these streams were of considerable size is indicated by the fact that the breadth of some of the outlets upon the face of the moraine is from 150 to 200 yards. These valleys are flat bottomed, 90 to 100 feet in depth in the deepest portions. The gravel mounds before mentioned were possibly formed by eddies in the stream. A similar internal drainage is found in the Ree Hills, Bald Mountains, and other interlobular moraines. Muskrat Lake is apparently formed by the partial filling of the principal channel by material brought in by the main western branch.

Among the bowlders found scattered in the Turtle Ridge two very large limestone bowlders were noted on the east brow of the hills, one 9 by 7 by 2 feet, the other 20 by 9 by 2 feet. There are no bowlders of red quartzite, nor of local Tertiary quartzite and sandstones. Ordinary granite and greenstone bowlders abound.

Extending southward from near the middle of the east side of Turtle Ridge is a low morainic ridge, leaving it at a very small angle, and running 3 or 4 miles farther south, and subsiding gradually to the level of the eastern plain in the northern part of T. 105, R. 65. Between this and the principal range is a shallow valley occupied by the headwaters of the west branch of the Firesteel. This subordinate ridge is very stony. Whether the explanation of its existence may be similar to that of the terrace north of Turtle Ridge is uncertain. It seems not unlikely that it is a portion of a faint minor moraine found between the first moraine and the second, or it may be a subglacial moraine due to some unevenness in the floor over which the ice was moving.¹ Extending from a point about a mile south of Crow Lake to a point 3 or 4 miles west of White Lake, in a nearly direct line, is the axis of another high and massive ridge, which we will call the south.

¹ Cf. Dana, *Am. Jour. Sci.*, 3d series, Vol. XXVIII, p. 230



VIEW OF OLD OVERFLOW CHANNEL IN TURTLE RIDGE.
Turtle Point on the right.

west Wessingtons. Its eastern face, like that of Turtle Ridge, is steep for about two-thirds of its height, then descends by gentle slope to the plain southeast. This range is highest in the middle, where it has an elevation of about 300 feet, in the vicinity of Ishams Lake. Its western slope is not more than half as steep as its eastern, and declines gradually to Smith Creek, about 5 miles northwest, where the stream is over 100 feet lower than White Lake in the plain east, inside of the moraine, fig. 11 (p. 37). While the range is massive, its summit is crowned with a few clusters of knobs, showing at a distance its morainic character. Among these knobs are the usual basins and ponds, the largest of which is Ishams Lake, sec. 16, T. 105, R. 66. Between Turtle Ridge and the southwest Wessingtons there is a broad sag, the summit of its bottom being about 100 feet above the plain southeast. In about the center of this pass or sag is a remarkable system of sharp, stony ridges from 10 to 30 feet in height, extending from near the southeast corner of T. 105, R. 66, in a curve corresponding to the lower portion of the sag to the southeastern part of Crow Lake. The general features of the system may be more fully understood from the accompanying map, fig. 4:

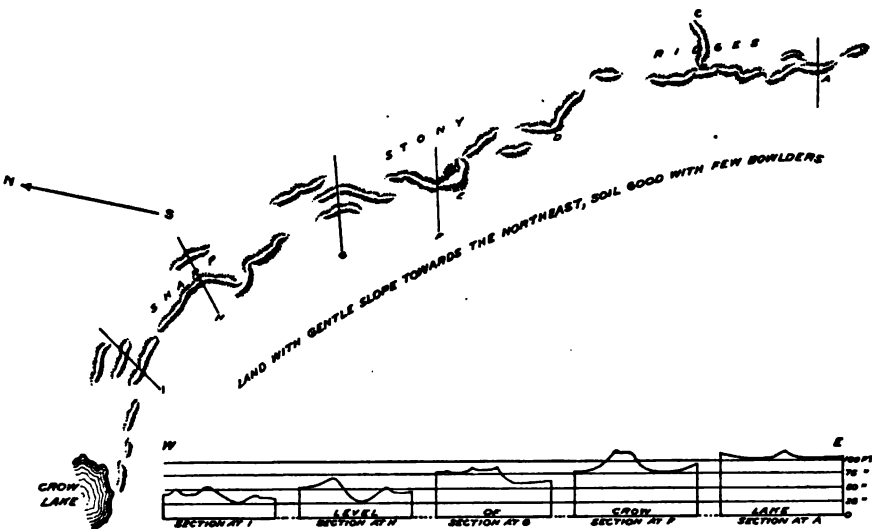


Fig. 4.—Map of osar-like ridges near Crow Lake.

These stony ridges are osar-like and are probably connected with former drainage from the ice sheet.

At the southern end of the southwest Wessingtons is a similar but less marked pass through the moraine, by which water probably escaped into a valley connecting with the head waters of Smith Creek. From this outlet the moraine is less conspicuous, evidently not having so high a pre-Glacial surface on which to rest. A scattered series of morainic hills may be traced southwest past Kimball to the middle of

the western side of T. 103, R. 68. This system of hills is from 2 to 5 miles in breadth, its inner and outer limits not being very clearly defined. Along its outer limit west of Kimball is a valley running southwest, connecting the valley of American Creek with Red Lake and the Missouri. The inner ranges of the moraine are but little higher than the subdued swells of the glacial topography upon that side. About 4 miles east of Kimball the railroad crosses two well-defined valleys, which head on the inside of the moraine. They doubtless indicate lines of drainage dating back to the time of the ice sheet. One of them connects with American Creek and the other with Smith Creek.

From near the middle of the west side of T. 103, R. 68, these morainic ridges begin to describe a semicircular curve toward the northwest, the outer range of which lies about along the east side of Red Lake. The principal ridge in the curve presents an abrupt and stony inner slope and a gentle outer slope, with few boulders. From the south-

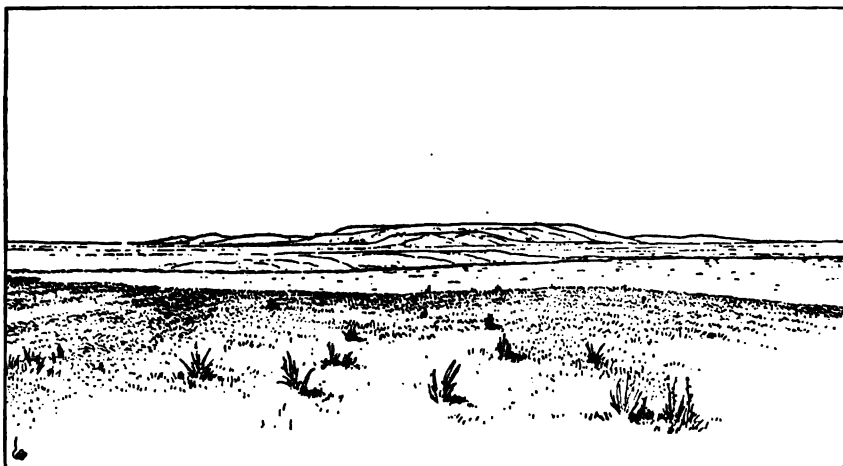


FIG. 5.—Portion of the moraine near Bijou Hills. v Moraine.

ern terminus of this semicircle, near the southern line of T. 103, R. 69, the moraine seems still less defined, but as it approaches the east end of the East Bijou it regains its character of broad, stony ridges separated by sags with ponds, the ridges being from 30 to 40 feet higher than the plain within. Lying against the eastern end of the East Bijou is a high north-and-south ridge over 100 feet in height (fig. 5), and apparently composed entirely of drift. South of the East Bijou the glacier at some time evidently pushed farther west, perhaps nearly to the western end, but such occupation was comparatively temporary. Masses of bowldery clay are found on the highest summit of the East Bijou, toward the south side and near the southwest angle of the hill. South of the Bijou Hills the moraine is again ill defined.

On or near the middle of the western line of T. 100, R. 69, is a well-

defined north-and-south ridge extending 2 or 3 miles. Its height is over 100 feet. Its northern end terminates rather abruptly amid a cluster of ponds of considerable size.

Extending inside of the principal portion of the moraine, from near the northwest corner of T. 101, R. 68, 7 or 8 miles, in a south-by-east direction, is a remarkable chain of lakes or lake beds occupying a broad, shallow valley. Southwest of the east end of the East Bijou is another cluster of lakes, with a valley connecting them with the head waters of Snake Creek. It is probable that these two systems of lakes occupy an old channel leading into Snake Creek.

Northwest, west, and south from the short ridge last described are lower stony ridges, which are doubtless a portion of the moraine. Besides these we find no trace of the moraine till we reach the hills around Cedar Creek, which occupy the central portion of T. 98, R. 68. The plain on the inside of the moraine is quite even, extending sharply down to the east bank of the Missouri. In it Pratt Creek has excavated a narrow valley about 200 feet in depth. East of its junction with the Missouri there is a high terrace, capped with an abundance of gravel and boulderets.

FROM PRATT CREEK TO RUNNING WATER.

The Cedar Creek Hills receive their name from a very short stream called Cedar Creek, which is surrounded by them. They extend some-

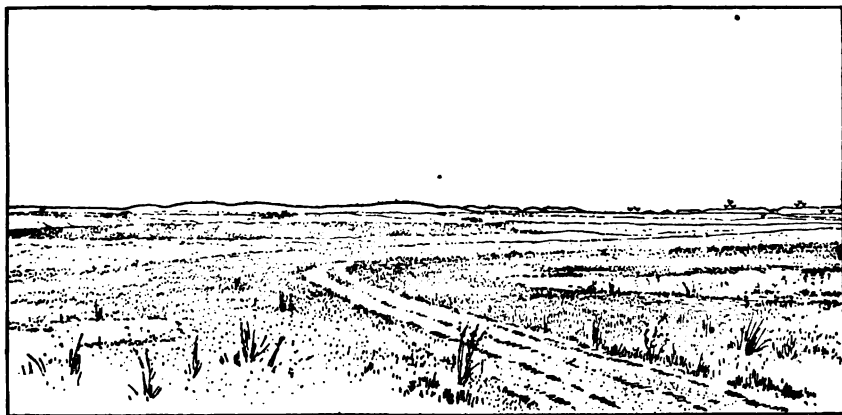


FIG. 6. —Cedar Creek Hills, from the north. v Pratt Creek. vv Missouri River. vv Driftless bluff.

what in the form of a V, with its apex pointing northeast and subsiding gradually into the plain on or near sec. 15, T. 98, R. 68 (fig. 6). The northwestern arm of the V, which is not very prominently developed, extends for 2 or 3 miles along the northern side of the stream. The southeastern arm extends in an irregular manner southward along the top of the east bank of the Missouri, connecting with the hills northeast of Wheeler. This continuation of the moraine has been under-

mined by an east bend of the river above Wheeler until apparently half of the moraine has been removed. Its appearance is shown in fig. 7. This view presents the nearest approach of the inside of the moraine to the Missouri River at any point between Pratt Creek and Choteau Creek.

From this point, which is on or near sec. 23, T. 97, R. 68, the inner line of the moraine may be described as follows: It extends east-southeast to the southwestern end of Lake Andes, thence from the southwest corner of sec. 12, T. 69, R. 65, near the south shore of Lake Andes southward along the east side of the township nearly to its southeastern corner, and thence south-southeast in nearly direct line to the middle of T. 94, R. 62.

The structure of the moraine through this portion is found to be a deep deposit of drift, overlapping hills of Cretaceous clay. The moraine

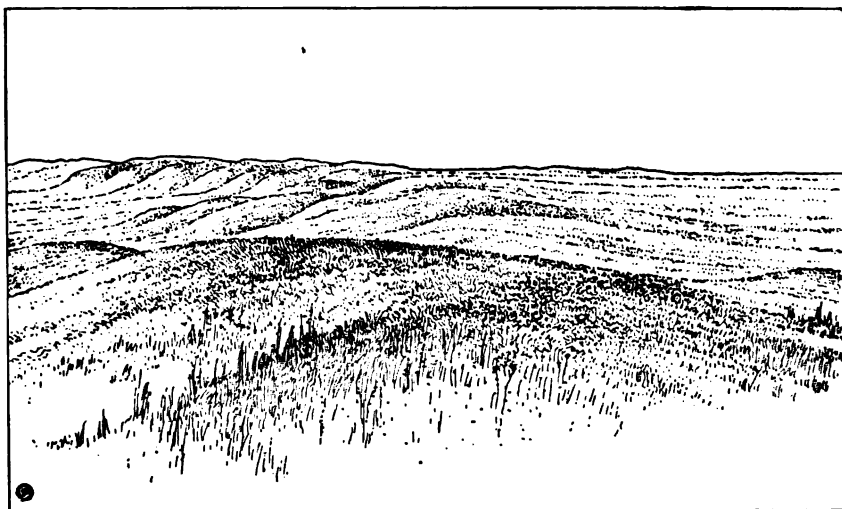
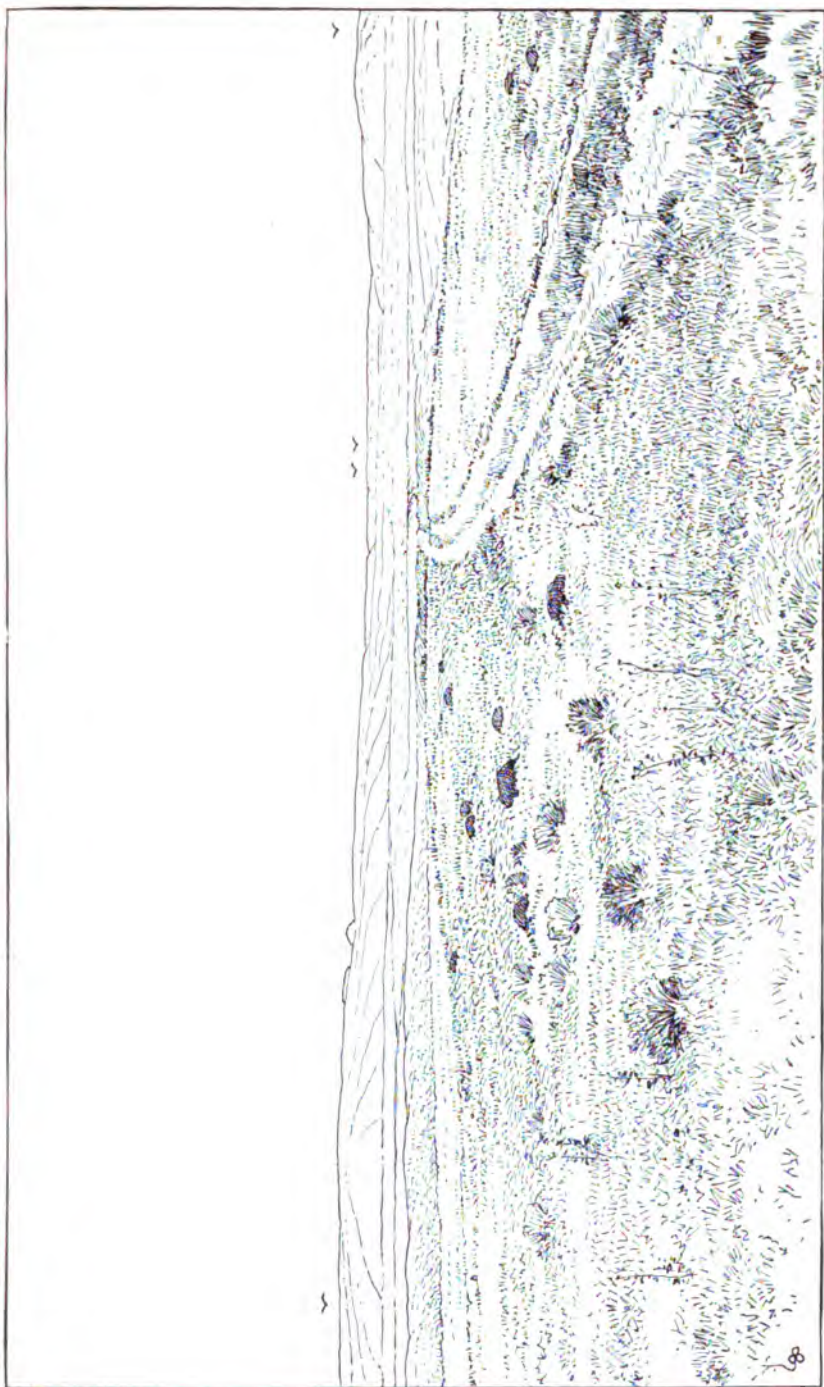


FIG. 7.—The moraine half eroded by the Missouri.

presents few knobs upon its surface. It may be described as a broad swell, with a somewhat abrupt slope toward the northeast and an irregular gentle slope toward the southwest, which latter is much seamed by short streams draining into the Missouri. It is interesting to find this portion of the moraine mapped as a ridge on Gen. G. K. Warren's map of 1857.

Through it are three important outlets, extending upon or a little below the level of the plain northeast. The first of these is now occupied by Pease Creek and another smaller stream. This outlet is from one-half mile to 2 miles in width, and is flat-bottomed, especially upon the western side, the eastern being occupied largely by a system of high, stony hills resembling osars. Another outlet is that extending southwest from the end of Lake Andes (Pl. IV). This also is occupied



LAKE ANDES OUTLET FROM THE NORTHEAST.
v v Bluffs across Missouri River, showing through Lake Andes Gap.

by a small stream, which flows along the western side, and also a dry drainage channel, a few feet in depth, from Lake Andes itself. The eastern side of this outlet also presents prominently the effects of running water, in the form of gravel terraces. Another less important outlet extends west-southwest from near sec. 25, T. 96, R. 65, till it joins the Andes Outlet before it reaches the river. From its relation to a grassy lake of considerable size northeast of it in the plain, I have called this Grass Lake Outlet. All of these outlets present the features of nearly straight troughs, with sides quite abrupt, especially the western. Their bottoms are in every case lower than the general level within the moraine, and slope more or less rapidly to the surface of the lower gravelly terrace described in Chapter V. Near the head waters of Sevenmile Creek, at the southwest corner of T. 96, R. 64, the moraine declines in elevation from 75 to 50 feet, and at the same time seems to broaden, and continues this character from this point to Choteau Creek. Several streams have their valleys heading in close to the northeast

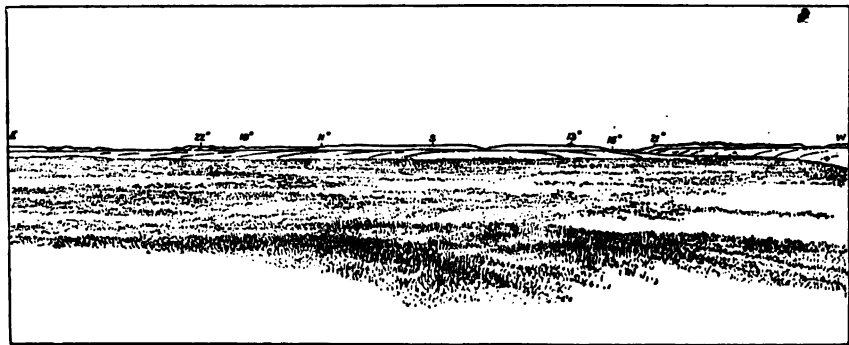


FIG. 8.—General view of the moraine from 2 miles south of Grandview. Numbers indicate degrees from south.

side of the moraine and probably were minor channels of overflow when the ice was forming the moraine. A distant and general view of this part of the moraine is shown in fig. 8.

A conspicuous point in this lower portion of the moraine is on or near sec. 30, T. 94, R. 62. It is situated some distance outside of the inner boundary of the moraine, so that it seems never, or very briefly, to have been covered by the ice. It presents the well-marked layers of the Bijou quartzite, lying in horizontal position, and scattered upon them numerous bowlders of all kinds. Its altitude is quite definitely determined to be 1,675 feet.

A view from the summit of the moraine shows, in general, a gentle slope down to the level of a high terrace along the left bank of the Missouri. This terrace averages over 200 feet above the river.

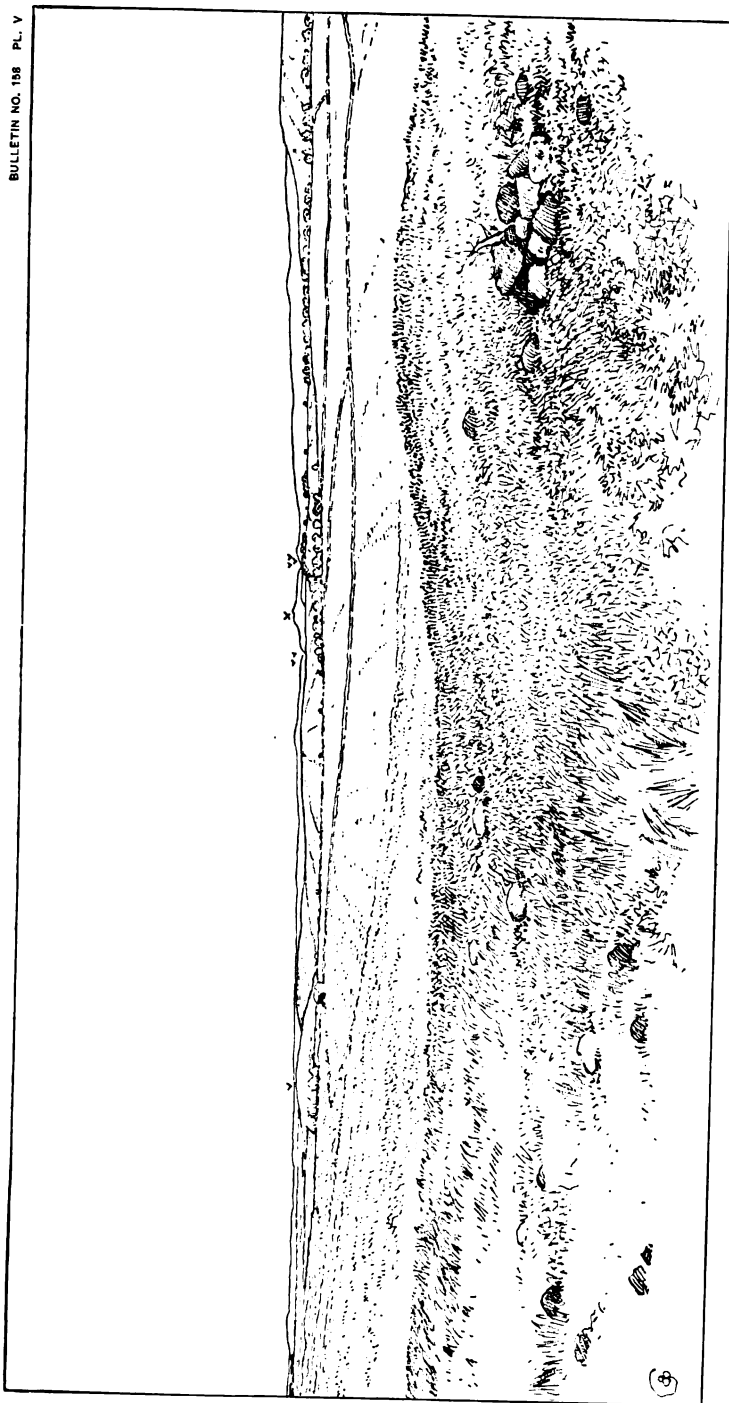
The valley of Choteau Creek, as it approaches the moraine, is from 1½ to 2 miles in width and flat bottomed, apparently marking another outlet, which, however, instead of going straight toward the Missouri, turns

eastward and joins a drainage valley from the interior of the Choteau Creek Hills. This latter valley, from the scantiness of water in it, is known as the Dry Choteau, while the more extended western branch is locally known as the Wet Choteau. The Choteau Creek Hills are a system of morainic hills surrounding the Dry Choteau. They extend north and south and are estimated to be 3 to 5 miles in width. Their northern end occupies the west half of T. 97, R. 61, and is surrounded with a broad, semicircular valley, in which rise the headwaters of Emanuel Creek on the east and an important branch of the Wet Choteau on the northwest. This valley is most abrupt on its outer side, and has a depth of 60 to 100 feet below the plain outside. The plain ends in a terrace-like edge, in some places considerably raised above the region farther back. This is markedly true of the portion east of the hills, near Aden post-office, sec. 1, T. 97, R. 61, where the surface suggests a minor moraine. The hills terminate southward in narrow but prominent ranges near the mouth of Dry Choteau. This is particularly true of hills on the east side of the system. East and southeast of that point there is a broad swell, evidently passed over by the ice and suggesting an advance of the ice farther west in its later occupation of the region. Perhaps the erosion of the waters escaping from the valley had removed the moraine on that side, so that the ice broke over the remainder into the drainage valley itself. That their location was probably predetermined by hills of Cretaceous clay is indicated by the reported occurrence of chalkstone some distance above their base at the northern end. This was not certainly determined to form a ledge, but was found in such quantity as to render it quite certain that such was the case. Several important lakes and marshes occur in the hills.

The ice sheet evidently very nearly surrounded these hills, as the small lobe extending east of them pushed through quite to Choteau Creek in T. 93, R. 61. It also reached nearly to the present course of the Missouri. There are, however, high northwest-southeast ridges extending from near the mouth of Choteau Creek to sec. 3, T. 92, R. 61, where they are more developed than farther west, rising over 150 feet above the plain to the northeast and estimated to be fully 400 feet above the river to the north. They are so cut by ravines from the river as to make their morainic character somewhat questionable. Fortunately, in an old well evidence was found of an ancient pond upon this hill, containing specimens of fresh-water shells and having every appearance of a morainic basin, which had been filled with earth 8 or 10 feet in depth.

EMANUEL CREEK GAP.

From this point no trace of anything that can be called a moraine is found until we reach the bluffs about 5 miles east of Bonhomme. Over this region, on the north side of the river, the plain, gently undulating, gradually subsides to the level of the lower, bowldery terrace,



JAMES RIDGE FROM THE NORTH.
 x Mount Pisgah. v Exit of James River through moraine. vv Exit of Beaver Creek. yy Entrance of Beaver Creek.

which has an altitude of about 200 feet above the river. The surface is somewhat lower in the vicinity of Springfield. North of Bonhomme, in the valley of Snatch Creek, the general surface is still more depressed, and abounds in low bowldery knobs. It suggests the filling of a pre-Glacial valley. This is further indicated by a gap in the chalk bluffs along the north side of the Missouri.

Upon the south side of the river, back from the bars and bottom land immediately adjacent to the channel, is a strip of country from 2 to 4 miles in width displaying very little drift, and underlain by chalkstone below and Oretaceous clays above, with much sand, probably of Loup Fork epoch, still higher. This region is very much eroded by small streams running north to the river. South of this strip of country there rises abruptly the northern edge of a table-land, built of beds of sand and gravel below and of loess with a few scattered bowlders above. The loess is much eroded, but its valleys extend away from the river into the branches of Bazile Creek. One peculiar feature of the northern edge of this table-land is the projection of high ridges of the loess extending $1\frac{1}{2}$ to 2 miles northwest, without diminishing in altitude, over the Oretaceous region before described.

It seems clear that in this gap of the moraine we have trace of a relation of ice sheet and river similar to that which existed between the Bijou Hills and the Cedar Creek Hills, though on a vaster scale; with the difference, however, that in that case the water was flowing rapidly transversely to the motion of the ice, while in this case it was, perhaps, discharging more in the same direction.

FROM BONHOMME TO SPIRIT MOUND.

The moraine appears on the north bank of the river, about 5 miles east of Bonhomme, in a high, broad swell, extending from the southwest toward the northeast, past Lakeport, which is situated on the inner crest of the moraine; but it rather abruptly turns eastward and declines in height near the center of T. 94, R. 57, where there seems to have been a broad outlet, or perhaps a tongue of the ice in the place now corresponding to the upper valley of Beaver Creek. Later there seems to have been much water flowing southeast over this area.

Near Lesterville a considerable cluster of morainic hills again appears, about 50 feet in height above the plain around them. These seem to be an interlobular portion of the moraine between the broad valley to the south and a narrower valley coming in from the north along their east side, or else a local development of a later moraine not usually appearing, possibly an earlier portion of the second moraine.

Again, beginning near the southeast corner of T. 96, R. 57, a high, sharp, continuous ridge extends in a nearly direct line to sec. 12, T. 94, R. 56, where it quite abruptly declines in height, apparently having been washed away by water from the west. Through this range is an interesting gap through which Beaver Creek crosses it toward the east,

upon sec. 28, T. 95, R. 56. South of this is a conspicuous peak, locally known as Mount Pisgah. An interesting drainage channel at high level crosses the moraine north of the gap on the west lines of secs. 16 and 21, T. 95, R. 66. A conspicuous view of this portion of the moraine from the inside is given in Pl. V, and from the outside in fig. 9. Another drainage channel at higher level runs south obliquely across it along the west line of sec. 16, T. 95, R. 56.

A few morainic points in a ridge running east-west, northeast of Lakeport, suggests the idea that the broad gap south of Lesterville may at one time have been occupied by a small lobe from the ice sheet west. The highlands west of Yankton descend in a long, gentle slope from the vicinity of Lakeport to Yankton. This slope is traversed by valleys extending south of east which bear traces of running water. There are gravelly knolls and terraces, especially toward the foot of the slope. From the gap east of Lesterville extends a broad valley, running southeast. Just southwest of James Ridge this also opens

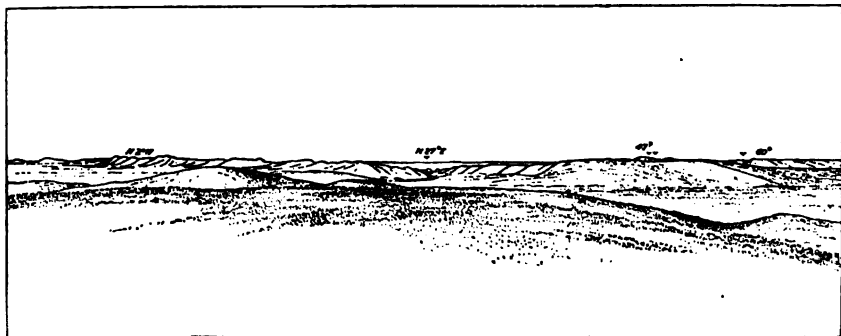


FIG. 9.—James Ridge, from the west. v Beaver Creek. vv Mount Pisgah.

toward the southeast upon a broad gravelly terrace, through which Beaver Creek in its lower portion has excavated a deep valley. James Ridge in its northern half seems to have been a narrow interlobular portion of the moraine. A lower bowldery ridge, somewhat detached, skirts its northern end much as in the case of the Choteau Creek Hills.

From a consideration of the topography of the gorge-like character of the trough of the Missouri from Bonhomme to Yankton, of the occurrence of blowing wells near Utica, and of the finding of fragments of quartzite like that of the Bijou Hills at the south end of James Ridge, it seems probable that before the advent of the glacier the Missouri, or rather the Niobrara, flowed northeast from Springfield and thence eastward north of Lakeport and Yankton to join the main river northwest of the latter place.

Extending along the east side of James Ridge, separated from it on the south by Beaver Creek, and turning east from the southern end of the higher part of James Ridge, is a morainic ridge, at one time thought to be a part of the outer moraine, but a more satisfactory



THE ATTENUATED MORaine NEAR VERMILION RIVER.

v Missouri River. v v Spirit Mound.

interpretation makes it a part of the second moraine, under which head it is further discussed.

East of Clay Creek morainic ridges appear again on or near sec. 26, T. 95, R. 54, where they are well developed along the east branch of Clay Creek.

From this point the more or less morainic west slope of the highland runs nearly northwest to the southeast corner of T. 98, R. 55. The west branch of Clay Creek flows along southwest of it in a southeasterly direction. Along the east branch of Clay Creek the chalkstone of the Niobrara group appears high up in the hills, rising some 80 feet above the waters of the stream. It is finely exposed as far north as sec. 17, T. 95, R. 54.

In the vicinity of Childstown post-office the moraine swings in a curve east, northeast, and finally around southeast along the west side of Turkey Ridge Creek, extending approximately parallel with the moraine just described, and forming with it a broad, high ridge, from 4 to 6 miles in breadth. Its eastern limit, corresponding to the inside of the moraine, extends from Spring Valley post-office, east of Irene, to the vicinity of Wakonda, then more southward and then southeasterly into the northwest corner of T. 93, R. 52, where it turns more east, declines in height, and becomes broken into detached hills, the last of which is Spirit Mound (Pl. VI).

This is a picturesque peak, rising nearly 125 feet above the level of the plain, upon sec. 14, T. 93, R. 52.

Turkey Ridge.—Turkey Ridge exhibits the usual features of interlobular moraines. It shows a core of Cretaceous chalkstone and clay, above which there generally seems to be a mantle of fine deposits, possibly eolian, probably of Tertiary age. In some places this is a fine silt, resembling loess, but more generally it is very fine sand. Some of it may have been derived from glacial action, deposited before the ice sheet covered this point. Above this rests a much thicker mantle of till, 50 to 200 feet thick, except where cut through by erosion. No trace of a composite character has been found in this, though it has been penetrated at many parts by deep wells. The more reliable source of water is the fine sand or chalk below. The water in the two may be confluent.

The main internal drainage channel is Turkey Creek, which evidently received its waters from the east side, where two prominent cols are found, one at an elevation of about 1,450 feet above sea level in sec. 30, T. 97, R. 54, another at an elevation of about 1,318 feet, a little south of Irene. Both of these, especially the latter, have been cut down nearly 100 feet since they were first traversed by the water. Traces of drainage from the west are found at two or three points, but the ice there was lower and soon the drainage was along the line of Clay Creek, which ran along the west side of the interlobular moraine. These two channels converge to the vicinity of Volin. Turkey Creek has a

naturally narrow valley, bounded by chalk cliffs rising from 50 to 100 feet above the water. Turkey Ridge is about 24 miles long and from 5 to 7 miles wide. Its surface is not very rough. Most of it is easily tilled, though in some places it is very stony. The prevailing stone is red quartzite. Its highest point is about 1,750 feet above tide, on sec. 5, T. 97, R. 55. From that place it declines quite regularly to about 1,400 feet for 2 or 3 miles west of Wakonda. A plan of it is given in Pl. VII; see also sections E-F and I-K with the general map (Pl. I). This is derived from the topographical survey of the United States Geological Survey made in 1896. In the later stages of the occupation of the moraine, as the ice thinned, the internal drainage ceased and the Vermilion lobe discharged along the line beginning in the eastern part of T. 97, R. 59, and extending to 2 miles west of Viborg, passing through the west side of T. 92, R. 52, thence nearly due south to sec. 9, T. 94, R. 52, thence southeast to the Vermilion River, passing just west of Spirit Mound.

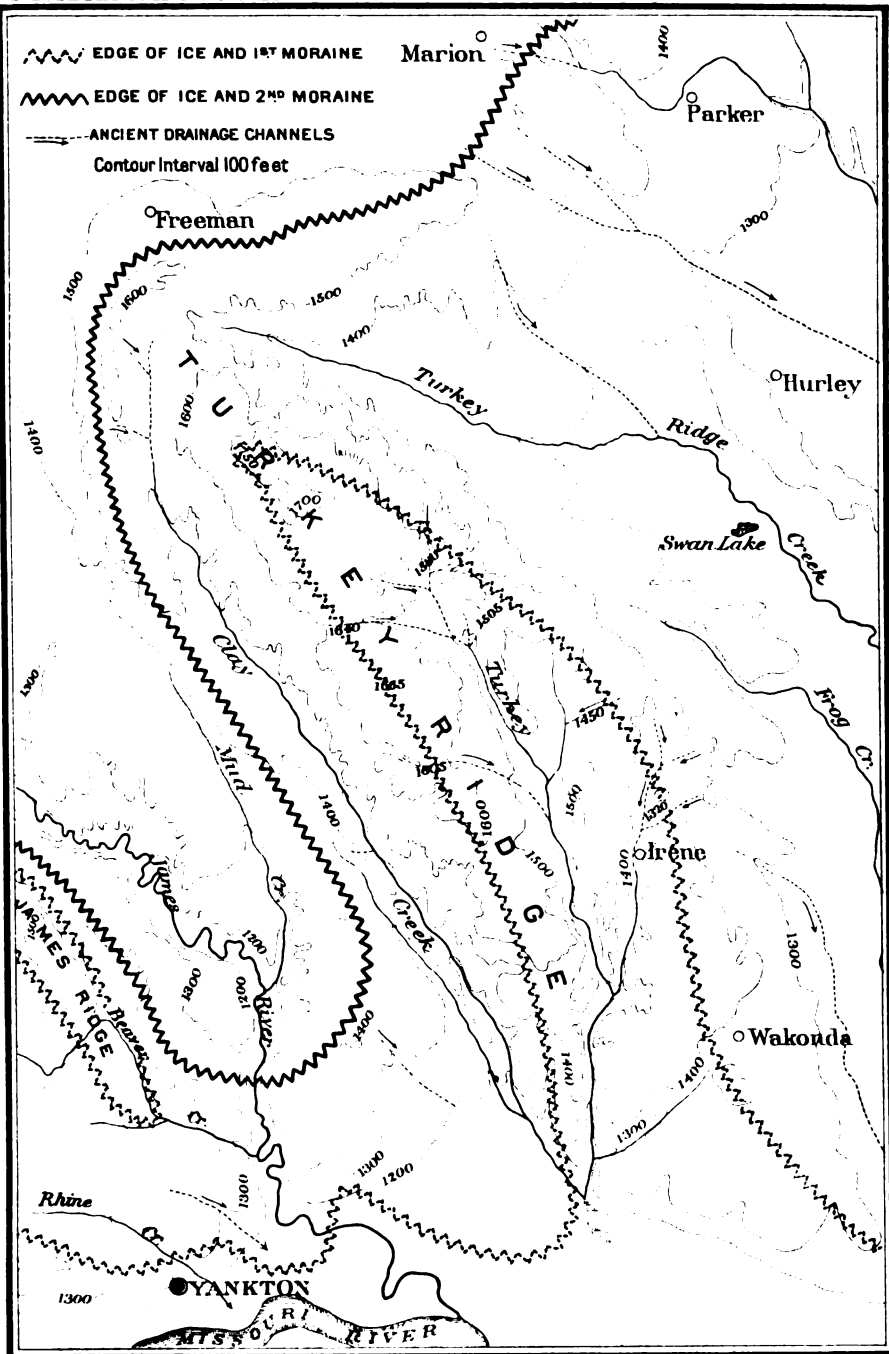
VERMILION GAP.

From this point there is a gap in the moraine about 8 miles in width. It is occupied by the very level plain along the Vermilion River. This plain extends southward and ends as a high terrace, the southern end of which extends from the mouth of the Vermilion nearly due east to the Big Sioux. It rises about 100 feet above the Missouri. This terrace, as exposed by cuts in the vicinity of Vermilion, is composed of blue boulder clay below, containing pockets of sand, and passing above into yellow pebble clay, and this is capped in places with a silt indistinguishable from loess. The surface of this terrace frequently exhibits basins similar to those found upon till; and from the relation of the terrace to the moraine it was probably occupied by a narrow tongue of ice running down the pre-Glacial Vermilion Valley into the Missouri.

FROM BRULE CREEK TO CANTON.

Along the west bank of Brule Creek, as far south as sec. 13, T. 92, R. 50, and still more prominent in the northwest corner of T. 93, R. 50, and the southwest corner of the township north, the moraine appears in a few scattered knobs of drift. Between these hills are evidently overflow channels from the plain northeast to the valley of Brule Creek. Some of their outlets are partially occupied by small lakes. These hills toward the north become connected into a broad swell composed of boulder clay, which rises and broadens toward the north and extends past Beresford, situated upon its summit, thence north and northeast to the middle of the southern line of T. 98, R. 49, where it terminates abruptly, overlooking a broad valley, which slopes from the plain northwest down into the valley of the Big Sioux at Canton.

This portion of the moraine is not traversed by overflow channels of any considerable size, at least none have eroded the moraine very deeply.



A. BORN & Co. Lith. Baltimore.

MAP OF TURKEY RIDGE, BY J. E. TODD, 1898.

There are, moreover, few knobs or morainic points exhibited by this portion of the moraine. It forms the western edge of a highland region occupying the whole area between it and the Big Sioux River on the east. This highland region is uniformly covered, especially upon the hilltops, with loess, some of the points of it rising higher than the nearer portions of the moraine. Branches of Brule Creek and the Big Sioux have eroded the whole surface of this highland so that the height of the hills above the valleys is often more than 150 feet. That there was more or less overflow across the moraine is indicated by numerous broad, marshy valleys extending from the summit of the moraine southward into Brule Creek. This is especially true in the vicinity of Beresford and south of Canton. At the northern end of the highland region it rises about 300 feet above the Big Sioux, and the valleys heading near the moraine are narrower and deeper than those farther south.

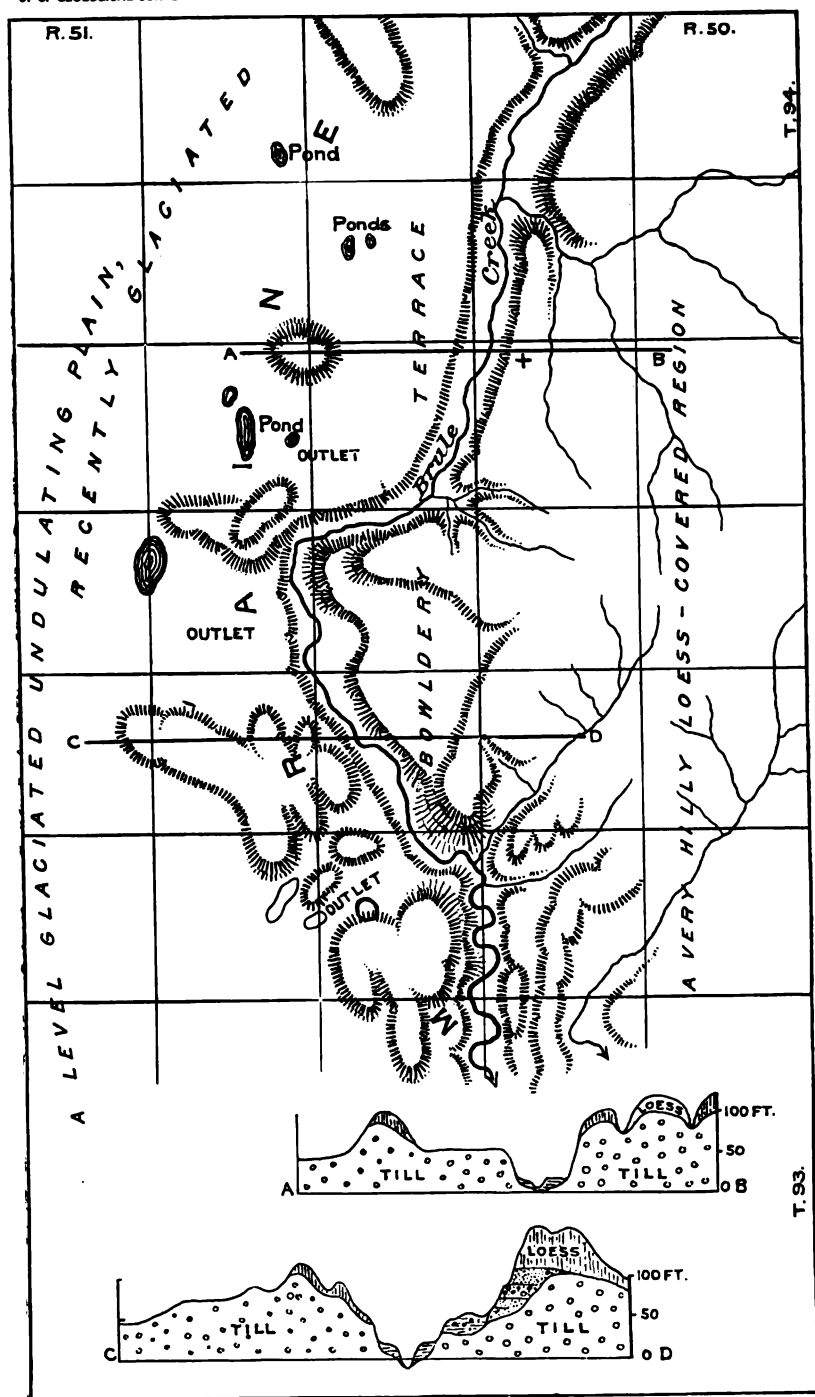
One of the most instructive portions of the moraine in this region, and indeed in any region, is that lying along the west side of Brule Creek, through Ts. 94, 93, and 92, R. 50. In the northern part of the first mentioned the moraine has the same features as near Beresford, and passes gradually into the eroded highland region farther east. This ends in sec. 17, and farther south there is an alternation of drainage channels with bowlder knobs. This is represented in part in Pl. VIII. These outlet channels are upon the same level as the plain farther west, and from 30 to 50 feet above the water in Brule Creek. In some of the wider it would seem that the ice occupied the channel and left ponds and boulders over the surface, as in the common glaciated areas. These knobs rise over 100 and 150 feet above the creek and from 60 to 70 feet above the surrounding plain. The channels are not all upon the same level, but are deeper toward the south. Their eastern surface is mantled with loam, indistinguishable from loess. It has not been found, however, more than 5 or 6 feet deep, and it is not difficult to account for the numerous cases by eolian action in time of northwest winds. East of the creek the till rises to about the same level as that which forms the body of these knobs. At several points along the creek, and 50 to 70 feet above it, there are thick deposits of sand and gravel directly underlying the loess, which is much deeper upon the eastern side of the creek. The relation is shown in one of the sections in Pl. VIII. Between secs. 8 and 9, T. 93, R. 50, the stream flows through a narrow gorge which seems to owe its character partly to the slipping masses of loess. From that point to secs. 24 and 25, T. 92, R. 50, there is no morainic material west of the creek, but at the latter point the hills again appear very distinctly on the west side of the creek. It is evident that Brule Creek began its course when the ice occupied the Vermilion Valley as far south as the Missouri, and that the ice rose nearly or quite as high as the general level of the loess farther east. The question presents itself whether the water during the early occupation of the moraine flowed as high as that level, so as to dis-

charge eastward over the loess of Brule Creek. There are some things, both at this point and in the vicinity of Fairview, which seem to indicate this condition. For example, the width of Brule Creek between secs. 8 and 9, T. 93, R. 50, seems too narrow for the width of the valley farther north and the numerous outlets leading to it. Again, south of Beresford, but more north of that place, while there are no prominent drainage channels, there are shallow ones which cross the moraine at a high altitude, some of them as high as and even higher than the level of the loess farther east. Moreover, northeast of Beresford there is a peculiar mingling of boulder knolls and loess, as if the loess portion of it had been deposited in the valleys of the till.

BIG SIOUX GAP.

From the northern end of the highland south of Canton to the highland south of Sioux Falls, on sec. 29, T. 101, R. 48, we have again a depauperated portion of the moraine. It is only represented by a few isolated hills lying along the west bank of the Big Sioux. They present at first sight the peculiar phenomenon of detached portions of the table-lands east of the Big Sioux. They rise to nearly the same height and are about 150 feet above the plain to the west. The first of these is about 1 mile northeast of Canton—a low hill composed largely of gravel, rising about 150 feet above the river. The second is a much more important hill, occupying much of sec. 6, T. 98, R. 48; the third a hill occupying sec. 20, T. 99, R. 48; the fourth, in or near sec. 15, T. 100, R. 49. These hills are composed of drift, and when of any size show basins indicating their morainic character. Between the highland south of Canton and the hill northeast there is a broad incline from the plain on the northwest to the level of the Big Sioux. Upon this slope two or three terraces may be traced. The plain on the northwest rises about 130 feet above the river. Continuous with the higher of these terraces, which is the more stony, is a long bowldery terrace extending down the Big Sioux, and gradually declining in altitude to the valley of the Rock River. It reminds one of the terrace on the Missouri extending from the mouth of Pratt Creek southward. The valley of the Big Sioux here is narrower, apparently not more than half the width of the Rock River. This is especially true in the vicinity of Fairview. This suggests its recent excavation, perhaps during the later occupation of the principal moraine.

North of Canton the plain to the west comes up quite sharply to the valley of the river, leaving a terrace-like edge, except in the vicinity of small streams emptying into the Sioux. East of the Sioux, as before intimated, the general level is from 200 to 250 feet above the river. No trace of Cretaceous clays was clearly noted along the Big Sioux above Canton till the northwest corner of Iowa was nearly reached. It is probable that they rise from 25 to 50 feet above the present stream. Northwest of Canton the chalkstone of the Niobrara group occupies



DETAILS OF THE MORAINIC IN UNION COUNTY, SOUTH DAKOTA. 

the bank of a small stream at a height of nearly 100 feet above the Big Sioux. There seems to be no evidence that any portion of the east bluffs of the Big Sioux represents any part of the moraine.

FROM THE BIG SIOUX TO VERMILION POINT.

Beginning on the west side of the Big Sioux, about a mile north of the northern boundary of Iowa, a high massive ridge begins to extend westward and southwestward around the Great Bend of the Big Sioux, and continues its westerly course to near the southwest corner of T. 101, R. 51. Thence curving northward, it crosses the Chicago, St. Paul, Minneapolis and Omaha Railway about 4 miles east of Montrose, then closely follows the east side of the East Vermilion, crossing the Chicago, Milwaukee and St. Paul Railway west of Winfred, and continues in that direction to a point about 12 miles northwest of Mad-

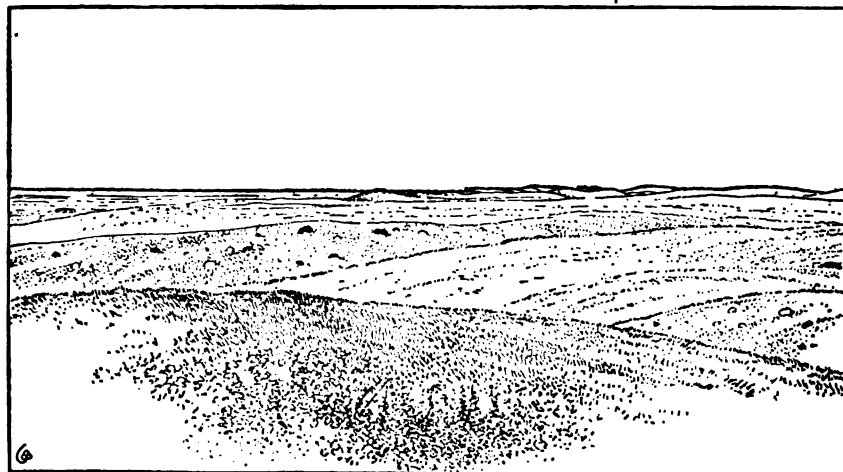


FIG. 10.—Inner slope of the moraine south of Wall Lake.

ison. The line indicated marks its inner slope. Its outer slope is less distinctly marked, being irregular, but usually with slight descent toward the north and east. Of the portion just traced, that immediately south of the bend of the Big Sioux is the lowest, rising only about 120 feet above the water in the river. It bears traces of several drainage channels, as though considerable water had been discharged northward from this point. About 3 miles southeast of Sioux Falls is the highest point east of the bend. It rises about 265 feet above the river to the east, or 165 feet above the Chicago, Milwaukee, St. Paul and Omaha station at Sioux Falls. In this elevated portion the moraine has been least modified, and therefore shows its usual characteristics—stony knobs and ridges, with ponds. The moraine has been crossed in the vicinity of Wall Lake, east of Montrose and east of Winfred. At the first of these points its height is 175 feet above the plain to the south-

west. East of Montrose and east of Winfred the altitude is about 200 feet. At all of these points the inner surface of the moraine is very stony and unusually marked with knobs, which are more numerous upon the inner slope than upon the summit of the moraine (fig. 10).

As one looks from the moraine toward the outside the view is like that of a plain, with numerous ponds in places. Elsewhere these ponds seem to have been drained by shallow channels of erosion, connecting with Skunk Creek. These channels are not uniformly from the inner surface of the moraine outward, but often parallel to it, or even occasionally flowing toward it. In these shallow valleys are sometimes found systems of elongated, sharp, stony ridges. One example was noted along a branch of Skunk Creek in the southwest corner of T. 101, R. 50. Another and more extensive system is found about 5 miles from Montrose, leading from a shallow gap in the moraine and extending to a branch of Skunk Creek. (Pls. IX and X.) A fuller description will be given in a later chapter.

The outer surface of the moraine gently declines to the surface of an undulating plain traversed by channels too large for their present streams. This portion of the moraine has no deep outlet channels traversing it. Its summit is not very rough, but from Hartford to Russell it is from 8 to 10 miles wide, and its outer slope abounds in prominent stony knobs and ridges interspersed with lakes.

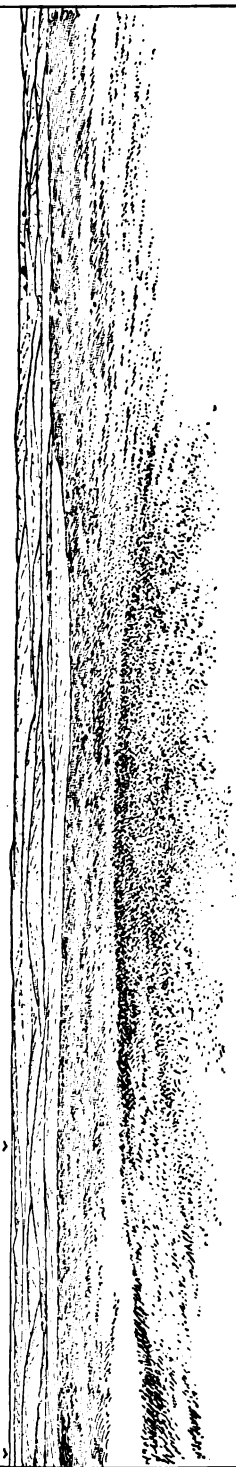
Vermilion Point is the termination of Vermilion Ridge, where it gradually subsides into the undulating plain on the north. Instead of resting upon the edge of an elevated terrace like Turtle Point, it lies on a plain running eastward. For this reason it is not nearly so prominent.

This completes the tracing of the outer moraine in the region chosen for consideration.

From Vermilion Point the moraine turns sharply east and northeast, and after crossing Battle Creek about 6 miles south of Madison, it quickly turns to a northerly course and passes 4 or 5 miles west of Volga. The southern side of this loop is slightly developed, or much eroded, but the eastern is very rough. It does not present the appearance of a broad swell, as in much of its course, but a disorderly mingling of frowning knobs and ridges, with narrow and broad channels which are frequently studded with lakes. The outer boundary of the moraine in this portion is marked by the northeasterly portion of Battle Creek and the flood plain of the Big Sioux farther north.

GENERAL CHARACTERISTICS OF THE MORaine.

The term *moraine*, although already frequently used in this paper, has not been clearly defined. It is a word introduced from the French, but may be traced with the Italian *mora*, a heap of stone, and the Spanish *moron*, hill or hillock, to the Latin *murus*, which not only has the primary meaning of "wall," but also "dam," "edge of a pot," etc.



CHANNEL, LAKE, AND OSAR RIDGES NORTHEAST OF MONTROSE.

v v Plain inside or west of the moraine.

Both wall and rim of a pot are instructive comparisons in forming an idea of moraine as used in this paper.

Moraine, as commonly used, includes all the *débris*, bowlders, pebbles, sand, and clay which is transported and deposited in various situations by a glacier. The moraine of which we speak in these pages is always the system of hills believed to have been heaped up around the edge of an ice sheet. Such hills are recognized as belonging to the moraine more by their relative position than by any one character which they bear individually. Each one is usually circular or lengthened parallel with the course of the system, abounds in bowlders, and has quite abrupt sides, but none of these characters are always found.

As a system the moraine usually presents these stony, knobby hills, mingled confusedly with circular and winding basins, which often contain water, but sometimes both basins and hills are very faintly developed, so that the whole constitutes a broad swell. The moraine is traversed here and there by transverse valleys, by which water escapes from the ice sheet. These may be of trifling size or many rods in width and cutting down through the whole height of the moraine.

The height of the moraine at any point is due, first, to the relative elevation of the pre-Glacial surface; second, to the amount of material pushed forward, which itself depends upon the pushing power of the glacier and the time its edge remains stationary; third, to the amount of material washed away; and, fourth, to the consistency of the material. Excess of clay or sand tends to produce a low and even moraine, while excess of stony material is favorable to the formation of a high and rugged moraine.

STRUCTURE AND POSITION.

A cross section of the moraine where least modified is a broad, low scalene triangle, the shorter side being inside, the longer, considerably

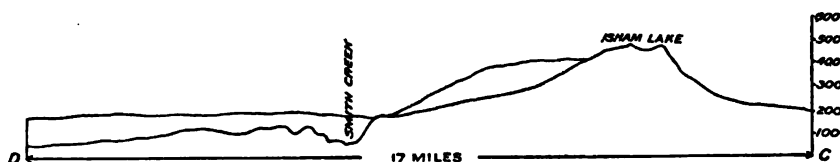


FIG. 11.—Section of southwest Wessingtons.

less abrupt, being outside. Much of the moraine, however, is so modified that these features do not appear. Portions best illustrating the character mentioned are found where the moraine is neither doubled upon itself nor closely adjacent to an important drainage channel, as, for example, the southwest Wessington Hills (fig. 11), the portion between Lake Andes and Choteau Creek, and the portion between Vermilion River and Canton, and again from Sioux Falls to Winfred. As has been already intimated, the pre-Glacial topography is believed

to have had great influence upon both the course and the character of the moraine. For example, the locations of Turtle Ridge, Choteau Creek Hills, and Turkey Ridge are doubtless due to the positions of high pre-Glacial buttes. The position of Vermilion Ridge seems rather determined by the distance which the ice sheet could force itself up an inclined plane. The subordinate lobes, as in the case of the Dakota lobe itself, were primarily determined by the existence of valleys down or up which the ice pushed its way.

HEIGHT.

The moraine has an elevation, above the plain inside, of from 50 to 400 feet. Its average height is about 100 feet. The extreme elevations, as, for example, in Turtle Ridge, are in localities nearer the center of the ice sheet, where we may suppose its thickness was greater and its transporting action more pronounced. The lowest portions are found apparently either where the ice sheet extended into ponded waters or where it was acted upon by floods of water coincident with or subsequent to its formation. An example of the first case is found north and south of the Bijou Hills. An example of the second is found in the lower portions of the James and Vermilion valleys. It seems not improbable that some of the less developed portions of the moraine are to be accounted for by their distance from the source of material and their transient occupation by the ice sheet. For example, the ice can hardly be conceived as occupying the moraine in the vicinity of Kimball as long as it did in the vicinity of Wessington Springs or of Lake Andes. It seems not improbable, also, that, other things being equal, if the drainage of an ice lobe is lateral an excess of material would be found near the termination of a glacier rather than in its lateral portions. This may explain the height of the moraine in the vicinity of Lake Andes.

The outer or principal moraine, in general, appears to increase in height toward the north, and still more toward the west. Both of these features will be seen from the following table:

Table showing heights of outer moraine.

Locality.	Elevation above—			Highest rocks near by.
	River outside.	Plain inside.	Sea.	
West of Russell.....	330	200	1, 825	
Northeast of Montrose.....		200	1, 740	
West of Hartford.....	289	200	1, 692	
South of Wall Lake.....	247	175	1, 650	
South of Sioux Falls.....	130	125	1, 519-1, 525	
Southeast of Sioux Falls.....	265	155	1, 555	120
Southwest corner T. 99, R. 48.....	200	110	1, 525	



CONTINUATION OF OSARS NORTHEAST OF MONTROSE.

Table showing heights of outer moraine—Continued.

Locality.	Elevation above—			Highest rocks near by.
	River outside.	Plain inside.	Sea.	
South of Canton.....	310	130	1,550	
Beresford	349	225	1,505	
Sec. 31, T. 94, R. 53.....	100	75	1,325	
Spirit Mound	215	90	1,361	18
Sec. 31, T. 94, R. 53.....	275	150	1,421	
Sec. 5, T. 97, R. 55.....			1,740	
Sec. 28, T. 95, R. 54.....	260	150	1,450	100
Sec. 7, T. 94, R. 55.....	250	100	1,440	
Mount Pisgah, (sec. 34, T. 95, R. 56)....	290	135	1,475	
Northwest of Lesterville.....		65	a 1,400	
Lakeport.....	310		a 1,500	120
Sec. 3, T. 92, R. 61.....	400	160	1,615	
Sec. 4, T. 95, R. 61.....	160	120	1,745	
North end of Choteau Creek Hills.....		260	1,800	150(?)
East center T. 95, R. 62.....	100	250	1,805	
Prospect Point (sec. 8, T. 97, R. 61).....			1,645	
Northeast corner T. 94, R. 63.....	400	200	1,620	
South center T. 94, R. 62.....	610		1,850	200
South of Lake Andes.....	605	390	1,845	
Sec. 6, T. 96, R. 66.....	450	260		55
Sec. 24, T. 97, R. 68.....	575	54	1,865	50
Sec. 28, T. 98, R. 68.....	697	175	1,986	
Southwest end of East Bijou.....	800	300	2,090	
East end of East Bijou.....		275	1,975	
North of end of East Bijou 2 miles....		75	a 1,775	
Hills near Kimball.....		50	1,820	
Southwest Wessingtons near Ishams Lake.....		300		
Turtle Point.....		475	1,954	100
Sec. 27, T. 108, R. 66.....		200	1,785	
Sec. 3, T. 107, R. 69.....	215	110	1,765	

a Estimated.

STONINESS OF THE MORAINÉ AND DISTRIBUTION OF BOWLERS.

The stoniness of the moraine seems to bear a direct relation to the action of water upon it. Where there are traces of torrential wash in the configuration of the country there is usually an increase in the number of bowlders; for example, in the internal drainage of Turtle Ridge bowlders abound upon the abrupt sides of the channels. And yet this was evidently only one influence among several. The occur-

rence of boulders in patches or nests, upon the moraine as well as upon the till, is probably due to some obscure segregating action of the glacier or of glacial streams.

The number of boulders in general in the Dakota moraine is much less than in moraines farther east, as, for instance, in Wisconsin. This is to be explained largely by the absence of boulder-forming rocks in the region. The glaciers over the whole Dakota lobe, with the exception of a few isolated square miles of Archean rocks, rested upon clay which was evidently easily eroded both by water and by ice. As has been already stated, the harder strata at the advent of the ice were, as a rule, found capping a few buttes. These buttes, in most cases, seem to have withstood the ice, and so their capping was not transported to any great distance.

Boulders of crystalline rocks, granite, greenstone, quartzites of several sorts, and of a very fine-grained, compact white limestone from the upper Silurian beds, occur everywhere, with little variation in their relative prominence. Some of the variations noticed in the character and distribution of boulders are as follows: Flesh-colored, fine-grained granite, black slate, and white and dark quartzites abound more along the western side of the Dakota lobe. The white and the yellow Silurian limestones were noticed in unusual size and profusion in Lake Andes Outlet and about the mouth of Choteau Creek, especially to the west of that stream. Boulders from 8 to 10 feet long and from 2 to 3 feet thick are not uncommon, while smaller ones are much more frequent. Their abundance so impressed me that in several clusters and heaps I counted them. In one, 16 out of 22 were limestone; in another, 8 out of 16; in another, 40 out of 48. Several others showed more than half limestone. The clusters counted were all on the lower bowldery terrace.

There are several kinds of rocks found in southeastern South Dakota which are adapted to form erratics. One is a siliceous rock of Tertiary origin resembling buhrstone, of fine texture, yellowish color, and usually marked with the stems of plants. This has been noticed apparently near position a little south of the Northern Pacific Railway, and occasional boulders, not often more than 6 inches in diameter, are distributed to all portions outside of the moraine, specimens being found, though never in considerable numbers, as far south and east as Page County, Iowa. A second rock is the greenish quartzite capping the buttes of the Bijou Hills system. This stone seems not to retain its hardness when exposed to the action of alkaline waters, for boulders of this rock are rarely found far from their original position without showing much disintegration. The next two, from the Cretaceous, furnish boulders, but they last for only a short time and are found rarely at much distance from their original beds. They are the "chalkstone" and the Dakota sandstone. Under the influence of moisture and shearing stress one quickly changes to clay and the other to sand. Fossils from

the one and pebbles from the other are not infrequently found. The largest bowlders from the Cretaceous, though rarely over a foot in diameter, are fragments of large bluish limestone concretions from the Benton, and usually show a septarian structure; they are not common, but seem quite durable. Interesting erratics, but rarely more than 4 inches in width, are derived from the Pierre and Benton. They are fragments of clay-ironstone concretions, which on weathering become hollow pebbles of limonite. The last is by far the most important. It is the well-known quartzite which exists in extensive ledges through southern Minnesota and westward as far as the vicinity of Mitchell. Its structure is favorable to the formation of bowlders, being naturally divided into blocks by numerous joints and seams of stratification. Furthermore, its indestructibility preserves the bowlders when passing through the ordeal of glacial and glacio-natant action. Red quartzite bowlders are rarely over 5 feet in length. The most western point where this rock was exposed to the abrasion of the ice is at Rockport. Another point farther west is found on Enemy Creek, in sec. 20, T. 102, R. 59, but from its lower position seems never to have been eroded by the action of the ice. The most western point in the moraine and the deposits outside at which red quartzite bowlders have been found is in a line nearly due south of Rockport, on How Creek, in northern Nebraska. It is not unlikely that an extended search in the Choteau Creek Hills may discover them there, but as yet none have been observed. From this point they increase rapidly in numbers toward the east. This distribution corresponds with the direction of the glacial scratches at Rockport and vicinity, which is southeast.

Another interesting point in the distribution of the red quartzite bowlders is that they are very abundant—70 to 90 per cent of all erratics—in the north end of Turtle Ridge, southwest of Turtle Ridge Creek and east of Clay Creek, but outside (north and west) of those streams they are rare. This is so noticeable, that it has attracted the attention of the residents of the region. This corresponds with the distinction between the first and second moraines.

CHAPTER III.

THE DRIFT REGION OUTSIDE OF THE OUTER MORAINE.

The drift, by which we mean any deposit, whether boulder-clay, sand, or gravel, containing erratics which show marks of ice action, extends for greatly varying distances outside of the moraine. As already stated, the erratics are mainly from the Archean and Silurian rocks. The region under consideration is naturally separated into the following divisions, which may be designated according to the portions of the moraine corresponding to their inner boundary.

What we shall, for convenience, style the Red Lake region, includes all territory lying outside of the moraine from Turtle Point and the moraine west to the vicinity of Pratt Creek, embracing—

The Ponca reach, extending from the mouth of Pratt Creek to the mouth of the Niobrara.

The loess region, extending on its northwestern border from the mouth of the Niobrara to Sioux Falls.

The Coteau des Prairies region, extending from Sioux Falls to Vermilion Point and beyond.

In each case the outer limit, as before stated, is the limit of the drift. Each region presents characters peculiar to itself. The first occupies an extensive external angle of the moraine and presents the peculiarity of driftless areas rising as islands above the sheet of investing drift. The second is long and quite narrow, being confined almost wholly to the present gorge of the Missouri. The third is covered with a continuous sheet of drift, and that again with a blanket of loam or loess. The fourth, like the first, occupies an extensive angle of the Missouri, but presents no driftless islands and is only partially covered with the loess.

RED LAKE REGION.

Topographically this region consists of a broad, basin-like widening of the more elevated or superficial portion of the valley of the Missouri, from the vicinity of the Great Bend to the vicinity of the Bijou Hills. It may be compared to a great lake bed in which wide, shallow channels have been eroded, and then at a later stage some of the principal ones have been narrowed and cut down to thrice their original depth.

The region is bounded on the north and east by the moraine. On the west its boundary may be given provisionally as follows: From the Missouri above the Great Bend along the west side of Medicine Creek

to the vicinity of Medicine Butte; thence past Red Butte south across White River; thence curving southeast to Waterholes Creek, 5 or 6 miles above its mouth; thence along the eastern side of its abrupt valley to the Missouri, which it closely follows down to the mouth of Snake Creek. This boundary is mainly determined by the distribution of bowlders, which are sparsely scattered over the older deposits of the country. The underlying rocks of the region are Pierre clays, which were evidently much eroded before the deposition of the drift. The Tertiary also is represented by quartzite, gravels, and probably some clays, capping the buttes along the southern and western border.

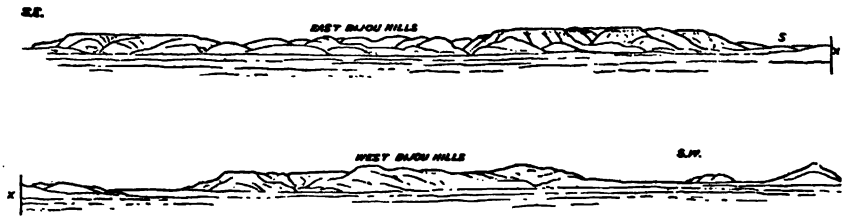


FIG. 12.—Bijou Hills, from the north.

The bottom of the pre-Glacial basin, as indicated by the course of the streams as well as by direct observation, was in the vicinity of Chamberlain. Around the edge of the basin to the west and south are isolated buttes capped with a greenish Tertiary quartzite. A range of these begins with the Bijou Hills and extends in a nearly continuous range westward. (See figs. 12 and 13.) Similar buttes are found southwest of the Great Bend, one of the more conspicuous being Medicine Butte, about 16 miles west-northwest from Chamberlain.

The drift which covers this region varies in thickness from 20 to 80 feet along the eastern side to merely scattered bowlders, as is usually



FIG. 13.—Buttes south of White River, from the north. v West end of Bijous. vv Gap of Waterholes Creek.

the case, west of the Missouri. These become fewer and smaller to a scarcely determinable edge. On the east side of the Missouri, between it and the moraine, is a nearly continuous sheet of till, which, as elsewhere, is yellowish above and reddish or bluish below. The surface of this till is unlike that which is found inside of the moraine in that it combines the usual features of erosive topography with faint traces of such basins as are found within the moraine. The average height of hills above minor valleys is from 30 to 50 feet. The elevation of the broad swells or uplands above the principal valleys is from 125 to 200 feet. Basins are rarely over 5 feet in depth and an acre in area. Moreover, many of these, by their position, suggest the idea that they are

due to the imperfect filling of old tributary valleys. They were noticed, especially along the northwest side of the Red Lake Valley, about 50 feet above its bottom. The accumulation of an indistinct terrace below that level may be conceived to have filled the side valleys at the mouth more than farther back. The surface is rarely too rough for tillage, except in the banks of present streams. The higher portions are covered, west and north of Red Lake, with 6 to 10 feet of yellow silt or loess. This hides boulders, which are seldom seen except below 50 feet above the bottom of Red Lake Valley. In places there are traces of a terrace at about that height, as has been already stated, but boulders are not confined to it, and are probably more noticeable below that level, because the loess has there been frequently removed. Everywhere there is a rich, black, loamy soil, except in basins and low flats, where "alkali" clay abounds.

To the general statement that the region between the Missouri and the moraine is covered with till, the following notable exceptions must be made: First, the region bounded on the north by a shallow valley running along the north line of Buffalo County from the Missouri to Boxelder Creek, thence along that stream on the east to its junction with Crow Creek, and thence by an undetermined line to a bend in the Missouri about 5 miles above Chamberlain. Over this region the drift is absent, except in the form of bowldery terraces along the principal streams, and elsewhere sparsely scattered boulders, perhaps one to the square mile. The surface of this region presents gentle declivities, except close to larger streams, where the underlying clay has been excavated into yawning ravines. The deep unbroken valleys lie about 100 feet below the broad rounded swells which separate them. The soil on the upland is a fertile, black, loamy clay. The sides of ravines are barren. The highest portions above Crow Creek are about 1,770 feet above the sea, or 450 feet above the Missouri. The highest summit south of Crow Creek and one a few miles northwest of Chamberlain may be a few feet higher, but neither rises to the height of the till near Bijou Gap.

Another and more perfect exception is found in the western Bijou Hills, including the western end of the East Bijou, the West Bijou, the buttes which stand in the gorge of the Missouri, and the summit of a smaller hill northwest of Bijou Gap. Upon all these no drift, not even scattered boulders or pebbles of drift origin, is found above the altitude of 1,885 feet, or 565 feet above the Missouri at Chamberlain.

The distribution of drift in the East Bijou is peculiar, and as it affords a contrast to the cases in hand, we will consider it more fully. The hill is a long, narrow butte, nearly 6 miles long and over a mile wide near its western end, and 300 feet in height. The eastern end is wrapped in a heavy covering of bowldery drift, as is all, except a sickle-shaped spur about a mile in length and nearly equal in height to the rest of the hill, which extends northwest from the body of the hill and

curves around toward the southwest. This spur, with a sharp southwest angle of the hill, incloses an amphitheater which opens to the southwest. The southwest angle of the hill is covered with boulder clay upon its southern and western slopes to the depth of about 30 feet. The top of the northwest spur is wholly without drift, except on its outer slope. In the amphitheater boulder clay rises to the 1,885-foot level in foothills which show a gentler slope than the hill itself. A conical hill lying a little detached from the north side of the hill is also driftless. The edge of the till on the flat summit of the hill ends in a slope to the northwest, its trend being northeast-southwest.

West of the Missouri only scattered boulders are found remote from the immediate vicinity of the gorges of the Missouri and White rivers, except a gravel-topped plateau several miles in extent southwest of the mouth of White River and south of American Crow Creek, 3 or 4 miles from the Missouri. Masses of drift, both gravel and boulders, are also found capping extensive terraces along both the Missouri and the White rivers from 200 to 250 feet above the present level. These will be more fully described in the chapter on terraces.

Along the south side of the old valley of White River, which is 2 miles in width, and in which the present gorge is excavated to the depth of 200 feet, extends a very conspicuous elevated plain covered with gravel, estimated to be 2 or 3 miles wide and extending along White River at least 5 miles. It is much eroded by ravines. Its pebbles are mostly of western origin, as is indicated by the great number of glassy, white, dark, and black quartz, and fragments of chalcedony seams. Granites and white limestone and other northern boulders are prominent on the sides of the ravines and scattered less frequently on the level surface. This plain lies about 350 feet above White River. Along the southern side of this plain lies a low swell, about 20 feet in height, on which there is a great profusion of boulders of all sorts; 28 granite boulders from $1\frac{1}{2}$ to 4 feet in diameter were counted in going up the ridge, one being 6 by 4 feet. A little south, and about 25 feet higher, blocks of Bijou quartzite are abundant, and Cretaceous clay occupies the eroded but gradually rising surface for 4 or 5 miles farther south. At that point a cluster of flat-topped hills rises about 75 feet above the surrounding plain and about 550 above the Missouri. They are considerably eroded, as though they were only the remnant of a much more extensive gravelly plain. Their preservation may be partly due to the greater thickness of deposit at that point, but are more probably due to the fact that they lie on the summit of the watershed between White River and Waterholes Creek. Their hills are capped with a deposit of western gravel 5 to 10 feet in thickness, resting on a drab-colored loam. Upon these hills were found a few boulders, one a dark hornblendic gneiss 3 feet in diameter, another of gray granite, smaller. Upon the crest of the watershed southeast of these hills several other boulders were found, but none to the south

or southeast, except two on the summit of a similar butte 3 or 4 miles southeast of the last-mentioned hills, which rise to the same level. Upon this were found a large boulder of white limestone, about 5 feet long, and a smaller one of gray granite. Similar buttes farther south, rising from the valley of the Waterholes, showed abundant blocks of Tertiary quartzite, but few pebbles, and no traces of northern drift.

Excepting the cases already mentioned, no northern boulders were found over the region south of White River. Immediately east of these hills is the wild gorge of Waterholes, and west the shallower valley of a tributary of White River. If traces of drift were formerly more abundant, as is possible, the great erosion connected with these valleys has removed them. The deposit along American Crow Creek is mostly on the south side, 24 miles from the Missouri. It closely resembles the extensive gravelly plain south of the White River, before described. It lies at an altitude of about 350 feet above the Missouri. It is about a mile in width and dips slightly to the north and east. The region between the lower portion of Medicine Creek and the Missouri has not been closely examined, but from its general appearance from the top of Medicine Butte, and its elevation, it is unhesitatingly put down as belonging to the scattered boulder region. In the valley of Medicine Creek, west of Medicine Butte, no trace of drift was found, but on the summit of the watershed, about 2 miles south of the peak, drift was noticed. A ride of a dozen miles to the southeast disclosed none except in the close vicinity of American Crow Creek. The general level of the gently undulating plain occupying the whole region is from 450 to 500 feet above the Missouri.

ANCIENT CHANNELS.

As before stated, the region is traversed by broad valleys. These are found for the most part to coincide with present streams. Their elevation above the Missouri is from 200 to 300 feet. One valley extends from American Creek at Pukwana southwestward past Red Lake in a direct line to the Missouri River. This channel is from $1\frac{1}{2}$ to 2 miles wide, and is occupied in its deepest portion by Red Lake, a shallow body of water 4 miles long and 2 miles wide. It is named from the abundance of reddish weeds which appear along its shores and cover considerable of its surface in the latter part of summer. Just east of Pukwana, and extending for 5 or 6 miles up American Creek, is an ancient lake, which has been filled. The level surface, the eroded spurs, and the sand and gravel struck within a few feet of the surface leave no doubt concerning the fact.

The heads of these various valleys connect in several cases with gaps in the moraine. Crow Creek, 5 or 6 miles southwest of Waterbury, crosses the moraine, which is there attenuated and broken. The northern and larger branch of Smith Creek in a similar way crosses, just northwest of Crow Lake, the faintly developed loop of the moraine, which

is pushed south down the west side of Turtle Ridge. The east branch connects with the internal drainage system of Turtle Ridge and the gap before described southeast of Crow Lake. Two of its southern tributaries rise near the moraine, one at the gap near White Lake and the other at a gap 5 miles northeast of Kimball. American Creek heads on the moraine near Kimball, and receives tributaries from the outer slope of the moraine farther west. Snake Creek heads near a gap or attenuated portion of the moraine south of the Bijou Hills. Another water course from the same stream extends north through Bijou Gap toward the lower part of the moraine, north of the East Bijou.

BOWLDER RIDGES.

A remarkable feature of these valleys in their upper course is the presence of numerous sharp bowldery ridges extending parallel with their course. These resemble those already described in connection with the gap near Crow Lake, and probably are of the same origin. They are from 5 to 15 or 20 feet in height, and frequently show a clustered arrangement. One system was noticed extending along the south side of the valley of Smith Creek near Lyonville. Another along the tributary valley from the vicinity of Kimball. Another, less conspicuous, was noticed along the American Creek Valley. In this case a tendency to a transverse arrangement was noticed. It is not unlikely these were formed in a different way.

OLD WATER LINE.

Another and still more remarkable feature, already alluded to, is a trace of water lines. This was first noticed in the vicinity of the West Bijou Hill. As one ascends its northern side the bowlders suddenly disappear at an apparently horizontal line. None are found upon the summit, nor anywhere upon the southern slope above that level. The drift masses on that side lie as low foothills between the higher spurs extending from the hill. Erosion has frequently made the line between the two very distinct. Upon the northern slope a line of more prominent foothills, or an eroded terrace, corresponding to this line, is quite distinctly shown. Around a high conical hill about 3 miles northwest of the gap the drift is found to disappear at about the same level. The border of the driftless region south of Crow Creek has not been examined with reference to this point. West of the Missouri the bowldery ridge, already mentioned as lying south of White River, is presumably near the same level; the distance between the two localities renders an exact determination with the barometer impossible. Other features of the upland of this region are provisionally referred to the action of currents of water. In the channel passing through Bijou Gap, a little south of the gap, is a marsh covering several acres. Southeast of the gap separating the West Bijou from the Brick Kiln Buttes are three or four slight basins trending southeast. Trailing southeast from each

of the Brick Kiln Buttes, though now detached from them by circumdenudation, is a long southeast ridge. One of these, where studied, showed itself to be capped with loess-like silt, although its core is largely Cretaceous clay. Southeast of Medicine Butte is a shallow marshy basin covering perhaps 2 square miles. Its longer axis points toward a sag in the low swell running east from the butte. South of this lake 3 or 4 miles are two much smaller marshy basins in a broad sag running southeast to the valley of American Crow Creek.

ELEVATIONS.

The elevation of the prominent points of the region, as given in the subjoined table, will furnish a more accurate idea of its topography:

Elevations in the Red Lake region.

[All are barometric except those marked r, which are derived from railroad levels.]

Locality.	Above the Missouri.	Above the sea.
	<i>Feet.</i>	<i>Feet.</i>
Missouri, foot of Great Bend		1, 334
Summit of drift terrace in the Bend	235	1, 590
Bluffs east of river	340	1, 695
Summit between Missouri and Boxelder, 10 miles east	425	1, 780
Boxelder Creek east-northeast	255	1, 610
Gravelly terrace just west	372	1, 725
Summit of moraine northeast	435	1, 790
Missouri at Fort Thompson		1, 341
Drift terrace east	320	1, 660
Summits 11 and 16 miles east	420	1, 760
Valley of Elm Creek between	285	1, 625
Boxelder Creek	210	1, 550
Terrace just east	335	1, 676
Moraine 4 miles east of Boxelder	425	1, 765
Medicine Butte	875	2, 100
Lake southeast	400	1, 725
Plain east, average level	430	1, 750
Bluffs west of Chamberlain	325	1, 645
River at Chamberlain		r 1, 321
Bluffs east of Chamberlain	325	1, 645
Summit 5 or 6 miles northeast of Chamberlain	460	1, 780
Gravelly terrace between Smith and Crow creeks	230	1, 550
Summit 5 miles northeast of Pukwana	380	1, 700
Pukwana	216	1, 537
Ancient lake northeast	210	1, 530

Elevations in the Red Lake region—Continued.

Locality.	Above the Missouri.	Above the sea.
	<i>Feet.</i>	<i>Feet.</i>
Red Lake	204	1,525
Kimball	458	1,779
Moraine near Kimball	500	1,820
Moraine southeast of Red Lake	325	1,645
Gravel-topped buttes 5 or 6 miles southwest of mouth of White River	570	1,880
Bowldery ridge northeast of last	510	1,800
Gravelly plain south of old valley of White River ...	360	1,665
Terrace of White River 6 or 8 miles above its mouth, capped with drift and loess	225	1,545— 1,500
Missouri at mouth of White River		1,308
Terrace north of mouth of White River	300	1,610
High hill south of the junction of Red Lake Outlet with the Missouri	460	1,765
Conical hill northwest of Bijou Gap	620	1,930
Moraine north of East Bijou	470	1,775
The driftless region 4 miles west of river	500	1,790
Bluffs near Rosebud Landing	450	1,740
River at the Bijous		1,290
Larger Brick Kiln Butte	710	2,000
Summit of ridge trending southeast	600	1,890
Summit of West Bijou	690	1,980
Bijou Gap	460	1,749
Upper limit of drift around western Bijous	590	1,880
Summit of East Bijou	710	2,000

NOTES FROM WELLS AND OTHER EXPOSURES IN THE RED LAKE
REGION.

Natural exposures displaying the drift are almost entirely wanting. Burrows of badgers and pouched-rats not infrequently display the sub-soil, but no more. Wells, the only artificial excavations available, rarely pierce through the drift, and are generally so curbed as to afford no opportunity for direct examination. The statements of well-diggers and other reliable persons who were present when the well was dug, with illustrative material around the mouth of the well, have been necessarily the main reliance in most of the cases tabulated below. Red Lake is given as a base of reference. Steep banks, mostly grassed over, have supplied a little information, which is in general valuable, but not exact.

Data from wells and other exposures in the Red Lake region.

[These data were collected before 1888. There has been no opportunity to tabulate later data.]

Locality.	Elevation above Red Lake.	Description.
	<i>Feet.</i>	
Bottom of ravine, 4 miles west of Pukwana.	45	20 feet deep; 6 feet in "soapstone."
Three miles west of Pukwana.	105	75 feet yellow till above, the rest blue pebbly clay; 1 foot water.
A few rods southwest of last, in a basin.	100	17 feet; plenty of water.
Pukwana, on terrace of an old lake.	10	12 feet yellow till above, 3 feet water; abundant water.
Three miles northwest of Red Lake, edge of basin.	75	3 feet black soil, 8 feet yellow till, limestone and other pebbles, blue till in the bottom.
Three miles west of Red Lake.	85	60 feet through yellow till and gravel, "no blue clay;" good water.
One mile south of south end of Red Lake.	40	16 feet soil, yellow till and sand, 24 feet blue till; no water.
Another near by.....	40	16 feet yellow till and sand, 20 feet blue till; no water,
A little west of last...	40	14 feet soil, yellow till and sand, blue till touched; plenty of water.
On flat southeast of Red Lake.	15	3 to 4 feet soil, 25 feet yellowish and reddish pebble clay, and sand below.
Five miles south-southwest of Red Lake.	160	A few feet yellow loamy till; pebbles not very numerous.
One-half mile east of last, in a basin.	160	Large pile of reddish-gray pebbly clay thrown out.
Five miles north of West Bijou.	215	5 to 6 feet "old soil," 6 to 7 feet yellowish silt with calcareous concretions.
Eighty rods north of West Bijou, on knoll.	270	6 feet yellow till, little soil (a cellar).
A mile west of southwest angle of East Bijou, on a ridge.	235	40 feet soil, then yellow pebble clay, then sand, then bluish dirt which grew harder, 52 feet soapstone.
At foot of southwest angle of East Bijou.	210	40 feet loose clay.

Data from wells and other exposures in the Red Lake region—Continued.

Locality.	Elevation above Red Lake.	Description.
	<i>Feet.</i>	
Two and one-half miles southwest of southwest angle of East Bijou.	180	Struck blue clay (Cretaceous) at 28 feet.
Sec. 28, 4 miles south of East Bijou, southwest slope of high hill.	280	All bluish clay.
Sec. 28, west center ...	245	30 feet yellow till, 25 feet soapstone; little water.
Sec. 28, southeast corner, in a ravine.	230	16 feet yellow clay, a little water, 15 feet blue pebble clay, 4 feet "black soil," "soapstone."
South of west end of West Bijou.	225	38 feet yellow pebble clay above, "black clay" below, then 2 feet of "soapstone."
Bluff 1 mile northeast of Chamberlain.	85	60 feet drift.
Bluffs east of Chamberlain.	115	5 to 10 feet loess, 70 to 75 feet drift, a reddish checky clay 50 feet below top.
Bluffs 2 miles south of Chamberlain.	145	5 feet soil and loess, 1½ feet yellow and drab dirty sand, 40 feet pebbly clay, quite gravelly, above drab clay.
Bluffs south of Red Lake Outlet.	240	20 feet drift above, yellow, loamy, bowldery clay below, a gravel bed, bowlderets, 50 per cent Bijou quartzite, 25 per cent white limestone, some bowlders 2½ feet thick.

EXPLANATORY HYPOTHESES.

Such are the general facts derived from a study of the region, and we naturally look for some hypothesis by which they may be explained. There are but two which present themselves. One is that this region—at least so much of it as is now covered with till—at some time previous to the formation of the moraine was covered by the ice sheet, which was either too thin or occupied the region too short a time to obliterate the pre-Glacial topography. The other hypothesis is that the dispersion of drift was accomplished by floating ice in an expansion of the Missouri, covering the region contemporaneously with the occupation of the moraine.

In favor of the first theory it may be urged that till is believed by many to be an ancient ground moraine; also that the occurrence of basins and bowldery ridges resembling those of glaciated areas can not be otherwise explained. Furthermore, topographical conditions seem somewhat favorable for the extension of a lobe westward between White Lake and the Bijou Hills, and such corresponds well with the observed distribution of till.

Against this hypothesis the following considerations may be urged:

First. If we make the extension of the ice correspond to the present distribution of till we must suppose such an extension both north and south of the Bijou Hills by an ice sheet, which, at least around the West Bijou, could not have been more than 100 feet in thickness, and extending on that level at least 3 miles around the East Bijou, while in less than 40 rods it must have risen from 100 feet to considerably over 300 feet in thickness. Or, if we postulate first a thin ice sheet of greater extent, and later a much thicker one of less extent, we find no adequate room for the drainage during the occupancy by the second ice sheet.

Second. Such an extension must have passed more than 15 miles beyond the moraine about Red Lake, while in the northern portion of the region it extended in some places less than 2 miles. Such difference in fluctuation at nearly or quite equal altitudes is incomprehensible.

Third. This hypothesis fails to offer a rational explanation for the scattered bowlders which cover by far the greater portion of the region under consideration.

Accepting therefore provisionally the other hypothesis, we may explain the facts discovered as follows: During the first advance of the ice sheet streams to the north and west of this region, finding their courses checked to the east, may have escaped around the edge of the ice; at first around north of the Wessington Hills; later down east of the Ree Hills southeast to White Lake; still later from the Great Bend to the White River and north of the Bijou Hills. Or, if we assume that the Missouri in this region dates back to pre-Glacial times, we may forego these suppositions. But finally the ice reached the Bijou Hills and soon after its greatest extent to the mouth of Pratt Creek. At this stage the water over the Red Lake region rose to its highest level, deposited the scattered blocks everywhere, and began the accumulation of till along the southeast side of the basin. The influx from the White River formed the highest gravel terrace, which was probably rendered the more easy by the derivation of material from the conglomerate strata of the buttes near by. The till filled to the water level in the vicinity of Bijou Hills. The accumulation of the till in this portion, rather than elsewhere, may be accounted for by the occurrence of gaps through the moraine—at that time, of course, larger than later—north of Kimball and north of the Bijous. The ice lobe of the Ree Valley may not have attained its maximum extension at this stage because of the greater elevation of its bed.

The outlet of this basin through the Bijous and around the ice at Pratt Creek probably soon cut down to the 350-foot level by the deepening of the channel west of the Bijous. The till continued to form in the southeast portion. The lower gravelly terrace south of White River was formed, as also the accumulation south of American Crow Creek. The Ree lobe with its branches had meanwhile reached its position, and the high bowldery terraces along the Missouri at the Great Bend and along Boxelder Creek were forming, and the upper portions of other important streams of the region were outlined. The formation of some of the osar-like ridges in these valleys are possibly to be referred to this stage.

During the thinning of the ice sheet these streams became unusually laden with silt, while ice blocks became rare, because of the stagnation of the ice, and a thin mantle of silt overspread the region below this level. As the melting of the ice sheet continued in its recession to the position of the second moraine, the channels were gradually deepened to about the 200-foot level. Most of the osar-like ridges were formed, and faint bowldery terraces of the Red Lake channel, which may be referred to a reassortment of local material rather than to that directly derived from the ice sheet.

More space has been given to this region because of its unusually clear bearing on the questions connected with glacial and glacio-natant action, which will be further considered in connection with the loess region, where the phenomena are more complicated.

PONCA REACH, OR REGION FROM MOUTH OF PRATT CREEK TO MOUTH OF NIOBRARA.

This region presents striking contrast with the last. It is narrow and straight. Its outer margin at no point is more than 3 or 4 miles from the river, nor more than 15 miles from the inside of the moraine. Its southwestern limit ends very abruptly along the edge of a high tableland corresponding geologically with the Bijou Hills, and rising abruptly 450 to 600 feet above the Missouri. The Missouri, from Pratt Creek to Fort Randall, lies in a narrow gorge, from 2 to 3 miles wide most of the way, with a high bowldery terrace along its left bank, at an elevation of 175 to 250 feet. Lower alluvial terraces are scantily developed. On the right bank the frowning edge of the tableland before mentioned rises abruptly from the river, except in the bend above the mouth of Whetstone Creek, where the bowldery terrace is finely developed, and at Fort Randall, where a high alluvial terrace is found.

Viewing the bluffs south of Pratt Creek Gap from about 12 or 15 miles north, they appear rising above the glaciated plain to about the same height as the Cedar Creek Hills to the left, which are, as before stated, a portion of the moraine; and they are at a lower altitude than the ancient water level in the vicinity of the Bijou Hills. From both

considerations it would seem impossible, under the lacustrine hypothesis, that they should not at some time have been more or less covered with drift; nevertheless, no drift is now found upon them, and not even in the valley of Whetstone Creek did a considerable search reveal any boulders or northern gravel. This is the more remarkable because the surface of the country drains southward into Whetstone Creek from the crest of the bluffs overlooking the Missouri River on the north.

The southwest side of the river was examined again near Fort Randall, and nothing was found higher than about 425 feet above the river which could in any wise be considered of northern origin except a very few scattered pebbles. The examination was continued for 15 miles, to the summit of the divide between the Missouri River and Ponca Creek, 600 feet above the former. Much of the surface traversed was about 450 feet above the river, and was crossed with shallow valleys extending from the northwest to the southeast. The surface was a dark loam, but the subsoil everywhere showed either the clays of the Cretaceous or, upon the high hills, the sands, marls, and gravel of the Tertiary.

From the vicinity of Fort Randall to the mouth of Choteau Creek the moraine is more remote from the river. Its outer slope, which shows the usual billowy appearance of hills, is ravined by two or three considerable brooks, which rise near the crest of the moraine and run nearly directly south to the river. Their upper tributaries occupy a more or less defined valley just outside of the moraine and parallel with it. This slope extends down to the high terrace before mentioned, which is here from 1 to 4 miles wide. This terrace shows a very even surface, sloping from a height of 250 feet at its outer side to about 200 feet along its inner edge. An interesting feature appears about 5 miles northeast of Yankton Agency, where the northern edge of the terrace is marked by an abrupt bank, facing southwest and extending for a mile or two. It is over 75 feet in height. Where the terrace was observed in the vicinity of Greenwood, near a stream, it was 130 feet above the river. There it is capped with 10 to 15 feet of silt, below which it is very gravelly and contains boulders for a dozen feet or so. Lower down it presents the usual features of till. About 4 miles west of Choteau Creek its edge is 200 feet above the river. Its surface is free from boulders and pebbles, being generally covered with a deep layer of silt. Below this a layer of 30 to 40 feet of loose yellow and reddish till prevails. Farther east, where its surface is ravined and cut into knobs, a wonderful profusion of limestone boulders is found.

Upon the south side of the river the table-land before mentioned retains its altitude and terminates on the northeast sharply with the top of the river bluffs. It continues with scarcely diminished height to the mouth of the Niobrara, where it terminates abruptly.

Along this portion of the river a very narrow terrace hanging to the abrupt south bank, as seen from a distance, was judged to correspond to that on the north side. From the mouth of Choteau Creek to the

mouth of the Niobrara the ice sheet seems to have abutted closely upon the river, much as at the mouth of Pratt Creek, but without pushing its moraine entirely into it, as it did a little farther east, in Emanuel Creek Gap.

Across the river is the eastern end of the southwestern table-land, rising abruptly from the junction of the Niobrara with the Missouri to the height of a little more than 300 feet. At this point it is a narrow, much-eroded ridge, but within 2 miles it attains an elevation of 400 feet and becomes a table-land more than 2 miles in breadth, which continues toward the west, both rising and broadening. Its slope is pronouncedly northward toward Ponca Creek. It is traversed by deep, narrow valleys running in that direction from the very edge of the bluffs overlooking the Niobrara. These bluffs are sometimes even lower at the head of the valleys, as though the escarpment on the south had moved northward since the valleys were formed. About 6 miles west of the mouth of the Niobrara heavy deposits of western gravel were found in knolls along the crest of the bluffs, about 425 feet above the level of the river at Niobrara. These are so left by erosion as to stand out conspicuously above the surrounding surface. A trip was taken along the line of the trail to a conical butte rising about 60 feet above the general slope around it and about 500 feet above the river. Upon it, and at several other points, numerous large blocks of Bijou quartzite are found, but not the first trace of either boulders or pebbles of northern origin are seen upon the general level of the highland. Both, however, are found scattered in considerable numbers over the spur at the eastern end to the height of 350 feet. It is a noticeable fact that they occur at the higher levels only in the sags upon the crest, where erosion would be least likely to remove them. They are very rarely found on the slopes of the bluffs or upon the flat at their foot. The limit of the drift at this point is estimated to be not more than 4 miles from the inner border of the moraine where it is developed on the opposite side of the river. The ice sheet must have been much nearer at its maximum, and when we remember that all the drainage of the vast western edge of the ice sheet must have passed this point, we are forced to inquire why the stream did not erode its way farther south; why it did not rise in its flooded stage so, as to carry the boulders (for there must have been some river ice, bearing drift, in glacial ice blocks) to a much higher level, to at least 450 feet, the level of blocks less than 4 miles southeast. It is clear that either this table-land was above the level at that time, so that they could not be deposited, or, if deposited at a lower level, erosion has been sufficient to wholly remove them.

The before-mentioned gravel beds along the Niobrara evidently correspond in elevation to the extensive sheet of gravel south of the town of Niobrara. From a distant view it is judged that these beds were connected through gravelly (?) knolls in the sharp bend of the Niobrara a few miles above its mouth.

LOESS REGION.

BOUNDARIES AND SURFACE.

Although the word loess may suggest the whole area covered by that deposit, the boundaries of that region are so vague that we adhere to our original plan of limiting our description chiefly to the surface covered with drift. We therefore turn our attention first to the—

WESTERN BOUNDARY OF GLACIAL DRIFT.

This also has been less accurately determined in this region than in the preceding. The principal difficulties met in an attempt to determine it are as follows:

1. The deep and almost universal covering of loess, which extends much farther westward.

2. The gradual passage of the northern or glacial drift into a western or fluvial drift, which has been found to occur along the principal streams from the west. The distinctions which have been relied upon in the determination of the former have been the occurrence of erratics of red quartzite and white and yellow Silurian limestones; also the striation and abrasion of pebbles peculiar to glacial drift. On the other hand, the western drift presents lithological characters similar to those which have been previously recognized in the discussion of the Red Lake region, and the pebbles are only waterworn.

3. The covering of the northern drift by the western. This may lead to wrong conclusions where exposures are incomplete.

4. The erosion and removal of the drift itself underneath the loess. This renders the upper surface of the drift very uneven, and because no drift is found upon the surface of a hillside one may fancy that none is present, where an exposure may reveal it as not only present, but rising high in the center of the hill.

So far as yet determined the western limit may be stated as follows: From the junction of the Verdigris with the Niobrara southeast, passing a mile or so east of Creighton, 5 or 6 miles east of Plainview, and east of Pierce to the vicinity of Norfolk; thence south along the western line of Stanton County, swinging to the east in Colfax County to the vicinity of Richland; thence in the same direction, passing 3 or 4 miles east of David City, south along the east side of Plum Creek to the vicinity of Seward; thence south and southwest, passing west of Norval post-office to the vicinity of Friend; thence southwest indefinitely. That one may estimate as justly as possible the value of this determination the subjoined data are given.

1. Localities visited which are beyond the drift, with a few others reliably reported:

- (a) No drift is found anywhere west of the Verdigris¹ nor between

¹ Later investigation has developed the occurrence of a few syenitic boulders upon the high terrace near Verdigris Valley, 180 feet above the stream.

the Verdigris and Bazile south of Sparta post-office. The Tertiary and Cretaceous rocks appear in that region in several places below the loess without the drift intervening. (b) On the south side of the valley, at Plainview, a bed of western gravel several feet in thickness was observed, but not the slightest trace of northern erratics. None have been found after a persistent search upon uplands for several miles west and north of that town. (c) The Yellowbank, north of Battle Creek, exposes a straight section 120 feet high, in which 60 feet of fine sand rests on the horizontal surface of 60 feet of compact drab-colored clay; no fossils or pebbles in either. On a side hill, a little northeast, considerable western gravel was found, but no northern erratics. (d) From Norfolk to Columbus no drift was noticed in passing on the cars and none learned of by inquiry. (e) On a high steep hill facing Shell Creek, near Platte Center, numerous pebbles and a few bowlderets were found resting on Tertiary clays. None were of distinct northern origin; none were striated, and most have a decidedly western character. (f) In numerous deep cuts north of David City and in the south side of the Platte Valley no pebbles of any sort were found. (g) Four miles south of David City a recently bored 80-foot well showed only a few western waterworn pebbles in a yellow clay. (h) The unanimous testimony of well diggers is that west of Plum Creek, which runs south from near Brainard to Seward, no "hard heads" or pebbly clay are struck in wells, though they are uniformly much deeper than those east of that line. In both regions the deposits are similar down to what is commonly called the "old soil." Below that point those west of the line indicated show sand only, while those east exhibit bowldery clay. (i) Nothing but western gravel was found in the vicinity of York, and general testimony is to the effect that no "hard heads" or pebbly clay are found west of Seward.

2. On the other hand, in the following localities the glacial drift has been directly observed. A few others of which reliable information was obtained are added, but carefully distinguished.

An extensive sheet of gravel was observed south of Niobrara. A thin deposit begins a mile east of Creighton. There are numerous exposures of yellow till from Osmond east for 5 or 6 miles, and there is abundant pebbly clay with bowlders at the insane asylum $1\frac{1}{2}$ miles northeast of Norfolk. "Hard heads" are reported as abundant 3 or 4 miles east of Pierce. Yellow and blue till with northern bowlders was found on Maple Creek in the northern part of Colfax County. Red quartzite pebbles were found in quantity 5 miles northwest of Schuyler. Northern bowlders and pebbles are abundant on the bluffs south of Linwood, and less prominent about the head of Bone Creek 5 miles east of David City, also south of Brainard in Butler County. Bowlders abound on hillsides and in ravines generally east of Plum Creek and of the Big Blue in Seward County. Drift is shown several feet in thickness in a high bank on the Big Blue 9 miles southwest of Milford. Red quartzite

bowlders and other traces of glacial drift were observed in abundance south of Pleasant Hill in Saline County, and are reported in the vicinity of Fairbury, Jefferson County.

EASTERN BOUNDARY OF GLACIAL DRIFT.

Theoretically the eastern boundary of this region should coincide with the extension in that direction of drift material which has been dispersed by ice of the Dakota lobe either as a glacier or as icebergs. On either supposition a mingling of material with that which was dispersed from the Iowa lobe would be unavoidable; consequently there would be more or less drift from the northeast in the area under consideration. So far as is known, no lithological distinction which would be decisive in this case can be drawn. Red quartzite and white limestone erratics are found inside both the Dakota and the Iowa loops of the moraine. The rock most likely to be of service in this respect is that from the Missouri Coteau, which resembles buhrstone,¹ but it occurs in such small fragments, and so rarely, that it must be of little service. The phenomena of most practical value which are likely to be found are striæ upon the underlying rocks, which show motion from a westerly direction. Topographical relations may also have some weight. So far as is known no such striæ are found in this region east of the immediate valley of the Missouri. Farther north, however, striæ are found in such relation to the Dakota loop of the moraine as will warrant us in placing the boundary which we seek far east of the Missouri. In Minnesota striæ from the northwest, or even from more nearly west, are found at Pipestone, also at a point 7 miles south of Pipestone, according to Mr. Warren Upham of the Minnesota survey. Numerous striæ have been observed also north of Valley Springs, South Dakota, from N. 62° W.

This gives us reason for locating, provisionally, the eastern boundary quite remote from the Missouri. It may nearly coincide with the eastern boundary of the loess deposit as given in a later section. A small bowlder resembling burhstone was found at Cherokee, on the Little Sioux, and another east of Shenandoah in Page County, Iowa, and it is not improbable that the eastern boundary should nowhere be nearer to the Missouri River than 30 miles.

As before stated, the southern boundary is arbitrarily set at about 100 miles from the moraine. The southern limit of the drift would lead us beyond the scope of this paper.

DESCRIPTION OF SURFACE.

Elevation.—The surface of this region is considerably higher than that within the moraine; south of Emanuel Creek Gap the difference is about 250 feet, and east of Big Sioux Gap 150 feet. Along its western

¹ This has been determined to be of Miocene age and formed apparently in marshes bordering the lakes of that epoch.

side the average altitude of the highest points is nearly 1,700 feet, while along the Missouri it is about 1,400 feet. The whole region slopes toward the south and east. This is shown by the following list of elevations. They are mostly barometric, but closely connected with points determined by railroad levels. Only such points are taken as lie in the general level of the country.

List of elevations in the loess region.

From north to south:	Feet.
Bluffs south of Herrick, Nebraska	1,750
Hills north of Plainview	1,825
Hills near Battle Creek	1,816
Plain south of Humphrey	1,690
Plain at Osceola	1,680
Plain at York	1,662
Plain at Fairmont	1,656
Bluffs at St. Helena, over	1,400
Summit of the divide southwest of Hartington	1,710
Hilltops southwest of Coleridge	1,840
Summit southwest of Northside	1,830
Summit 8 miles south of Stanton	1,800
Bluffs 5 miles northwest of Schuyler	1,610
Plain at David City	1,619
Higher knolls	1,650
Plain at Germantown	1,584
Plain at Dorchester	1,501
Hills west of Ponca	1,375
Hills west of Emerson	1,630
Hills east of West Point	1,526
South of North Bend	1,450
Hilltops near Wahoo, over	1,300
Plain at Cheney	1,435
Knolls at Cheney	1,460
Southeast of Valley Springs	1,510
Plain at Warren, Iowa	1,465
Hill east of Akron	1,415
Hilltops south of Blair, Nebraska	1,350
South of Louisville	1,225
Near Turlington	1,195
From east to west:	
Bluffs near Platte Center	1,645
Bluffs near Schuyler	1,610
Summit near Mapleville	1,432
Summit west of Kennard	1,285
Hills west of Calhoun	1,250
Guthrie, Iowa	1,290
Plain at Friend, Nebraska	1,575
Knolls at Friend, Nebraska	1,600
Plain at Dorchester	1,500
Hilltops northeast of Crete	1,450
Cheney, general level	1,435
Cheney knolls	1,460

It may be conceived that at least the western portion of the region was at one time a nearly level plain, out of which the valleys of the present streams have been excavated. The original surface of the plain has been quite perfectly preserved away from the larger streams. Between the Platte and the Elkhorn this is true as far east as the headwaters of Maple Creek. South of the Platte the plain extends as far east as David City and the Big Blue. Traces of the plain, in the form of high flat-topped hills, are found as far east as the Missouri and beyond; but the whole region was probably never filled to a level plain. Several things seem to indicate that when the region was first vacated by the depositing waters it was not a completely filled basin. We would not assume to decide between a lacustrine or fluvial deposition; probably both played a part. We proceed to give some of these because they also illustrate the peculiarities of the present surface.

Basins and knolls.—Even when the surface is most nearly a perfect plain, as in the region west of the Big Blue, there are shallow basins with clayey bottoms and corresponding swells. Along south of the Platte about Osceola the same is true, and farther eastward about David City both features are upon a grander scale. Some of the basins are more than a mile in breadth and the knolls and ridges from 25 to 40 feet. The aspect suggests the former extension of a shallow lake in which there were low islands or bars. Farther north, about the headwaters of Logan Creek, similar features, though much modified by erosion, are noticed in the topography, but erosion has cut down the basins, leaving the hills much more elevated, though still showing the same isolated and irregular arrangement. Doubtless winds have had a mild dune effect upon the loess.

Elevated ridges.—In the northern part of the region under consideration a conspicuous feature of the topography are the high, somewhat discontinuous northwest-southeast ridges. One extends from near the mouth of the Verdigris to the vicinity of Bazile Mills. Another begins east of Santee Agency with a lofty spur running out several miles from the northern edge of the table-land north. It extends down into the southeast corner of Knox County. Another begins southeast of Yankton and extends southeastward to the West Bow. Another begins near St. James and extends southeast into Dixon County, and possibly into the Winnebago Reservation.

These ridges are more narrow and conspicuous toward the north, and may possibly be looked upon as the high watershed separating the intervening streams. Their surface features are doubtless due to erosion, but the prevalence of this direction remains unexplained. We must look for it in some peculiarity in the original surface where the courses of the present streams were begun.

In the list of elevations given, the summits of these ridges were taken rather than of lower surfaces between.

Ancient channels.—This directs our attention to another problematic

feature. This embraces certain channel-like valleys which are found in northern Nebraska crossing the divide between the tributaries of the Missouri which run in a northerly direction and those which have a southerly direction. Their characteristics are best preserved upon the watersheds, because there they are least modified by erosion. The one passing near Coleridge, Nebraska, may be taken as a type of the whole. It connects Bow Creek with the upper waters of Middle Creek, a branch of the Logan. It is a valley from 3 to 4 miles in width, showing two or three subordinate channels or intervalles running approximately parallel with one another and depressed from 30 to 50 feet below the broad, flat ridges between them, which at one time may have been bars or islands in the ancient stream. These terrace-like ridges are covered with a thin layer of loess, under which is found gravelly clay 20 or 30 feet higher than the channels. In the bottom of the channels, after penetrating the soil, which is deep and rich, sand of indefinite depth is struck. Coleridge, which occupies the summit of this channel upon the divide, has an altitude, according to railroad levels, of 1,672 feet. The altitude of a high loess ridge southwest of Coleridge is 1,800 feet, and a similar ridge 5 miles east of Coleridge is about 1,825 feet high. Northwestward from Hartington the general surface is much eroded and distinct traces of the channel are not found. However, there is nothing to forbid the opinion that the channel formerly extended in that direction.¹

A similar channel passes from the Verdigris to the Bazile at Creighton, thence southeast up the latter stream to Plainview, where it is $1\frac{1}{2}$ miles in width, and does not present the complex appearance which was noticed at Coleridge. From this point it continues in a direct southeasterly direction to the north branch of the Elkhorn at Pierce.

A smaller valley, which passes from the east branch of the Bazile at Kemma southeast to the north branch of the Elkhorn, presents similar characters. These channels in Nebraska are all much eroded toward the northern end by existing streams.

Areas sloping away from principal streams.—Another character of the topography, which is unlike that usually found in the chance arrangement of streams upon an even plain surface, is the frequent occurrence of drainage from the immediate vicinity of the principal streams to some subordinate stream. This is remarkably true along the southern side of the Platte Valley. For nearly 100 miles the waters falling immediately south of the edge of the bluffs, instead of making their way into the Platte, are carried away southward into the tributaries of the Big Blue. Even where small streams turn northward, as Bone Creek and Skull Creek, the bluffs rise precipitously next to the Platte Valley, and the waters, which eventually flow northward, are first turned south-

¹Since the above was written, facts and considerations presented by Gilbert, Bain, Udden, and others have led the writer to give greater prominence to wind action in explaining the irregularities of surface mentioned.

ward through the narrow valleys of these creeks. So with the Elkhorn on its southern side from the vicinity of Wisner to Scribner, the land slopes from the very top of the bluffs southward and southwestward. Along the northern side the same feature prevails. Such subordinate streams as Plum Creek, Ouming Creek east of West Point, Bell Creek, and the west branch of the Papillion, draw from the very summit of the bluffs along the Elkhorn. The same feature may be occasionally found along the present valley of the Missouri, but its greater depression and the probably less original elevation of its bluffs render it less prevalent and less evident. On a grander scale the whole of the northeastern corner of Nebraska may be instanced as an example of this feature, sloping, as it does, away from the eastward-flowing portion of the Missouri. Along the east branch of the Big Sioux, from the northern line of Iowa southward, a similar relation carries the waters from its near vicinity into Rock River.

All of these features, when traced back to their beginning, point toward inequalities in their original surface of greater or less magnitude. Further reasons for believing that this original surface was uneven will be found in the section treating of the relations of the loess to the drift.

Principal streams.—The central stream is the Missouri. Its valley north of Yankton resembles in every respect that in the regions already described, but east of Yankton it puts on quite a different appearance. While its bluffs are still high along the south side, they show no older formation except near their bases. The valley suddenly widens to a breadth of from 8 to 10 miles. This breadth it retains to the mouth of the Big Sioux, where it is somewhat increased. South of Sioux City it attains a breadth in places of more than 15 miles. At Blair the valley begins to narrow, and near Rockport, southeast of Calhoun, it is about 3 miles wide. It is a significant fact that at this point the Carboniferous limestone begins to appear near the water level. Farther south the valley is very rarely more than 5 miles wide, and while the slope of the stream from Sioux City to this point has been about 6 inches per mile it now increases to 1 foot per mile, which it continues to the southern line of Iowa. The valley of the Missouri is bounded everywhere in the loess region with steep bluffs of that material, rising 250 to 400 feet above the low, flat, bottom lands between. Where they have been longest subject to erosion the loess, which usually constitutes from one-half to three-fourths of the height, stands at an angle of from 40° to 60°, while drift makes a much smaller angle with the horizon, and the older rocks stand out as a shelf or shoulder.

Three important streams enter this region from the west—the Niobrara, the Elkhorn, and the Platte. The first, which barely enters, flows in a narrow valley 300 to 400 feet deep. The other two have very wide valleys, especially in their middle course, and are depressed from 250 to 300 feet below the general level. Their slopes nearly coincide with the slope of the region.

Tributary streams and creeks are numerous throughout the whole region. They are fed by perennial springs, and usually run in narrow ravines from 5 to 20 feet deep.

Terraces.—Although the subject of terraces will be treated more fully in another place, a few words seem called for in this connection. Along the principal streams the present flood plain is at an elevation of from 5 to 20 feet. The bottoms of their valleys are principally occupied by land upon this level. Traces of other benches from 15 to 30 feet are not infrequently of considerable extent. Besides these more recent terraces there are conspicuous traces on most streams of a terrace at from 60 to 100 feet above the present stream. Traces of this high terrace are found along the Missouri from Herman to De Soto, in Washington County, Nebraska; also in the vicinity of Fort Calhoun it is finely exhibited for several miles. At North Omaha and at Bellevue it has considerable extent and an altitude of about 50 feet.

Along the Platte we find a high terrace on the north side of the present valley extending from Hall County, where it is low and much obscured by sand hills, to the vicinity of Fremont, where it has an altitude of about 80 feet. Its northern edge is marked by the lower course of the Loup River, Shell Creek, and Maple Creek. There are ancient channels connecting these streams with one another at their nearest points. Its width is from 3 to 4 miles. From the vicinity of North Bend an old channel, 8 miles in width and on the same level with the terrace to the north, extends southeast along the east side of Sand and Wahoo creeks to the vicinity of Ashland.

Along the Elkhorn the terrace before mentioned, north of Fremont, extends northward on the west side of the Elkhorn to Scribner. Little trace of this terrace has been found above that point, partly because it is obscured by sand hills, partly because the region has not been fully examined upon that point.

Traces of this high terrace are found along Bazile, Beaver, Bow, and Logan creeks in Nebraska. In Iowa traces of it are found along the Big Sioux near Beloit and Fairview, and along several of the streams on the east side of the Missouri, which have not, however, been examined sufficiently to warrant a more complete description.

Elsewhere, and in general, the topography of the loess region finely illustrates the principles of erosion when applied to a homogeneous deposit. Remote from streams the hills have a gently rounded form, extending to the edge of the deep ravines which furrow the bottom of the valleys. These ravines increase in depth toward their head, where they terminate abruptly with perpendicular or even overhanging banks. Toward the principal streams the slopes of the hills gradually become steeper. Where undermined by eroding streams they frequently present bare perpendicular faces 20 to 50 or even 100 feet in height. In general the topography is of the erosive type prevalent in massive sandstone regions, for the loess resembles sandstone in its resistance to the various

weathering agencies. From its tendency to stand in steep slopes along the streams Professor Swallow, of Missouri, early named it the Bluff deposit.

Sand hills.—Beneath the drift over much of this region is a deep deposit of fine sand presumably belonging to the Pliocene epoch. In the northern portion of Cedar and Knox counties the lower valleys are much widened by the unusual recession of their sides, which may be ascribed to their undermining because of the presence of this deposit. The sand is considerably mingled with the soil and gives a pleasing smoothness to the landscape.

This sand deposit comes to the surface and occupies much of the country west of the Verdigris and the ancient channel before mentioned, which runs southeast from Creighton. The western boundary of the loess is there, and as far south as the Platte, obscured by the advance of the sand eastward. Sand hills and "clay hills" are indescribably mingled. The "clay" closely resembles, if it is not identical with, the loess. It probably is a deposit of the Loup River epoch. The ancient channel between Creighton and Pierce, more especially south of its summit, shows an interesting series of transverse ridges of sand, vast ripples, as it were, rising from 25 to 60 feet above the intervening clayey meadows. They are at quite regular intervals of $1\frac{1}{2}$ miles. Traces of sand are found in the wash of the hillsides as far east as Cedar County. At several other localities also there occur sand hills which, though formed by the wind, have had their material brought into the region by the instrumentality of streams. The Elkhorn and the Platte, flowing through sandy regions, accumulate large quantities of sand in their bars and bottom lands. When this sand is driest and most widely exposed the whole region is subject to prevalent winds from the northwest; the result is that, wherever these streams run toward the southeast for some distance, large quantities of sand are blown from the valleys out upon the upland. In this way one may take a map and with considerable confidence tell where such sand hills will be found. They have been observed occupying several square miles south of Stanton. They are prominently developed, and are more conspicuous because of their elevation east and southeast of West Point. They are frequently interspersed with small ponds. South of the Platte they have been observed near the mouth of Bone Creek northeast of David City, and in a very extensive area south of Kearney. They also occur in corresponding positions along the branches of the Loup River. Much of the broad valley north of the Platte is occupied by sand hills.

DRIFT DEPOSITS OF THE LOESS REGION.

The drift of this region may become the subject of much controversy as concerns its origin. We therefore propose to present, as completely as our space will allow, the data which have been gathered.

TILL.

The lowest and most important formation is here, as elsewhere, the till. It presents the usual appearance of a homogeneous matrix of clay containing pebbles and bowlders scattered through it, with rarely any trace of stratification or segregation of any sort. It also contains irregular masses or pockets filled with stratified gravel, sand, or silt.

Color.—The prevalent color, when unaffected by weathering or leaching, is a bright lead blue. Sometimes, however, it is a dull grayish brown. It abounds, especially in its lower portions, in white pebbles of limestone and quartz, which in a fresh surface present a striking appearance upon the blue background. The upper portions of the till, where it has been long subject to weathering, or where the frequency of porous layers or seams has carried the surface waters into the clay, are of a yellowish appearance, which below sometimes shades into a reddish color and above into a dull buff.

Joints.—The clay always presents a jointed appearance, these joints running in all directions, dividing a deposit into polygonal masses. These masses are continually subdivided as the process of weathering goes on. In the freshly exposed blue till these masses may be 3 or 4 feet across, and the seams are correspondingly prominent. They appear in some cases, which we may consider an earlier stage, as mere cracks cutting the mass irregularly. They more frequently show traces of accumulation in the form of thin calcareous or selenite plates. Seams have been found where the selenite plates were from one-eighth to one-half inch in thickness. In some cases the selenite shows a coating of flour-like gypsum, and in some cases, toward the surface of the deposit, where it is more changed, the whole seam is filled with such material. The color of the blue clay adjoining these seams gradually changes through different stages to a dull yellow. As the selenite plates increase in thickness these weathered portions as a rule also increase in thickness. Some of the measurements of observed cases are as follows: Measuring from the center of the seam either way, one-eighth inch flour-like gypsum, one-eighth inch drab clay, three-fourths inch bluish, then the surrounding blue clay; another, one-half inch cream-colored core, 3 inches yellow clay, 2½ inches whitish yellow, then the blue clay. More convincing evidence in favor of the conclusion that the yellow till is merely the weathered portion of the blue could scarcely be imagined. This change of color in this case corresponds with what is uniformly observed of the drab-colored layers of the chalkstone, of the similarly colored beds of the Benton and the Pierre clays, and also of the blue limestone of the Carboniferous and Paleozoic rocks generally.

Local indications of subaqueous origin.—There are several features of the till in this region which favor the conclusion that it is of subaqueous origin. While the previous description may be taken without qualification as to general structure, there are exceptions found, as

follows: (1) Its colors are sometimes arranged in a horizontally banded manner. This has been observed repeatedly along the Platte southwest of Fremont, where ashy and chalky layers occasionally appear; (2) while the erratics usually have no perceptible arrangement, they are sometimes arranged in horizontal lines; perhaps a dozen pebbles lie within a few feet of one another upon the same level, where as many more of similar size could not be found in as many yards; (3) another fact which, although it does not pertain to the structure of the till, has an important bearing on the question of its subaqueous origin, is the resting of the till upon the nearly horizontal surface of stratified sand and clays of pre-Glacial origin without their slightest distortion.

The upper portion of the till which presents the yellowish colors frequently abounds in calcareous concretions, some of irregular globular form, others, occupying the larger seams, of sheet-like form. Sometimes these concretions have to a considerable degree the appearance of disintegrated chalk.

RED CLAY.

The second member of the drift we will designate as the red clay, for no other characters seem more constant. It usually lies above the till. It is never below it, but sometimes is found where no till occurs, and it is sometimes wanting between the till and the loess above. Its more common characters, besides its brownish-red color, are: (1) It is much more clayey than the loess above, and, especially in its upper portion, becomes more loamy than the till below; (2) it uniformly presents a stratified appearance, layers of clayey silt alternating with thicker layers of purer clay. Erratics even several inches in diameter frequently appear in it, and usually in a more or less stratified condition. These are found in greater abundance toward the base of the formation. Its upper portion, for several feet in depth, may be entirely free from them. Its stratification may be obscure either when it has been somewhat weathered or when the exposure is of a more clayey stratum.

Its upper surface is nearly always distinctly marked, but its lower surface not infrequently passes into the till without a clear line of separation. This feature has been noted at lower levels near the principal streams. In the northwestern portion of the region under consideration it is overlain by a heavy deposit of gravel, but as a rule the loess rests directly upon it. The darker and redder shade of this member is without doubt due to the greater abundance of ferric oxides, and may indicate that the formation has been more exposed to the air. It may find an analogy in appearance, if not in origin of color, to the weathered portions of ferruginous sandstones.

GRAVEL AND SAND DEPOSITS.

The third member of the drift is composed chiefly of gravel and sand beds, which also abound, usually in their upper portions, with bowlders.

These occur mainly in the vicinity of the Missouri and the Big Sioux, their greatest development being in Knox County, Nebraska, and Minnehaha County, South Dakota. In the former locality it constitutes the bulk of the drift.

RELATION OF THE DRIFT TO THE UNDERLYING FORMATIONS.

The formations found beneath the drift are arranged in general in strips extending north-northeast to south-southwest. First in the northwest corner of the region come the Pliocene sands and clays, 50 to 100 feet in thickness. Their southeast margin, at least of their thicker development, extends approximately from near the northwest corner of Dixon County past Coleridge, Stanton, and Columbus, southward. An area along the Split Rock in Minnehaha County, South Dakota, is also doubtfully referred to this epoch. Similar deposits have been observed also along the Big Sioux east of Canton, and nearer Fairview, South Dakota, and northwest of Sioux City; also near Lemars and Cherokee, Iowa. This formation along the Missouri rises to an elevation of nearly 400 feet above the river in Knox County, Nebraska, and diminishes in altitude to the east. Along the line outlined as bounding its thicker development it does not diminish much in altitude toward the south. The Missouri, Elkhorn, and Platte southeast of this line have cut through it to the older formations below, and, it would seem, have removed much of its thickness. The Niobrara chalkstone appears next east of and underneath the Pliocene. Its eastern limit approximately extends from near Brandon, South Dakota, southward along the Big Sioux, where it is exposed at Canton and Akron, also at Ponca, west of Dakota City, at West Point, Skull Creek, Milford, Pleasant Hill, and beyond. The Benton clays are but feebly developed. The next formation, the Dakota sandstone, appears quite prominently. Its eastern limit extends from near Dakota City past Tekama, Louisville, Beatrice, and beyond. It is found also in detached areas near Lewis and Red Oak, and northeast of Sioux City, Iowa. The upper Carboniferous underlies this and extends farther west than the east limit of South Dakota. It occupies the remainder of the loess region in Nebraska and Iowa, with the exception of small detached areas of Tertiary of indefinite extent.

These rocks seem to have been excavated in the form of a broad valley along the Missouri, with its bottom from 15 to 150 feet above the present level of the Missouri, but in the bottom of this valley the immediate channel of the Missouri and other streams seem to have been excavated to the present depth or even to a greater.

The drift, where it has been observed, rests upon the surface of the underlying formations without disturbing them, except in a few rare cases. The general fact may be illustrated by numerous sections taken from Knox County, Nebraska, and a few from southwestern Iowa. In the former locality the drift is found in some places resting upon a

deposit of volcanic ashes more than 3 feet in thickness, which, though very friable, shows no disturbance. About a mile east of Osmond it was found resting on a gray pebbleless clay, and conformably. In Mills

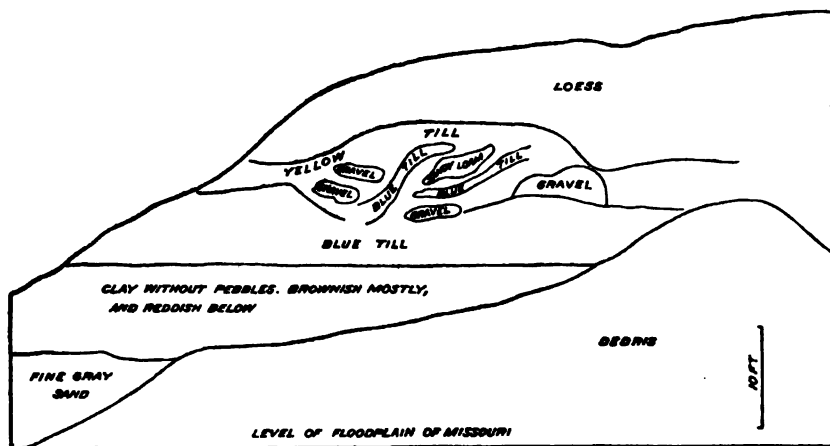


FIG. 14.—Exposure showing base of the till north of Pacific Junction, Iowa.

County, Iowa, typical blue till was found resting upon a grayish-brown clay from 5 to 10 feet in thickness containing no pebbles, and this in turn upon sand (fig. 14). Neither showed signs of disturbance. Near Ben-

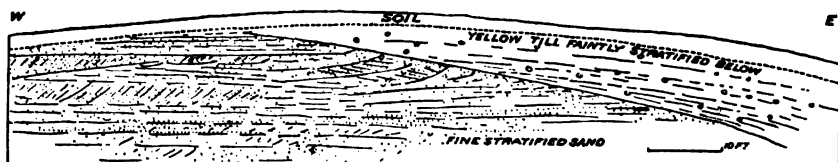


FIG. 15.—Exposure showing base of the till near Berks, Nebraska.

nett and Roca, Nebraska, drift was found resting upon Carboniferous clays without apparent disturbance. Near Berks, Nebraska, it was found resting upon an inclined surface of stratified sand with no traces of disturbance in either (fig. 15).

STRIATION OF UNDERLYING ROCKS.

While what has been given seems to indicate the general gentle position of the drift, at least in deeper or more protected localities of the old surface, there are a number of cases where great force has been exerted in a horizontal direction. Striae have been observed in the following localities: About Sioux Falls the surface of the quartzite is planed and striated generally toward a direction varying from S. 8° E. to S. 43° E., but some were from the west. Southeast of Sioux Falls, about the northwest corner of Iowa, the surface of the quartzite is smooth and striated in a similar manner, in direction from S. 8° E. to S. 53° E., the majority of cases corresponding with the course of the Big Sioux.

A few miles north of Valley Springs striæ varying from S. 8° E. to S. 63° E. were abundant on the polished red quartzite. So far as is known, no distinct striæ have been observed on any other formation except the Carboniferous limestones south of the Platte in Nebraska and adjacent portions of Iowa. Very faint indications of motion from the north-northwest of superincumbent blocks of bowldery clay were noticed south of Roca, Nebraska. At Bennett, about 9 miles east, the surface of the limestone was found planed and covered with striæ indicating a movement S. 41° to 43° W. This was on the northeast side of a hill looking toward a valley opening in that direction. A rod or two west of that point a few striæ toward S. 17° W. were found, and still farther west at one point striæ were found toward S. 61° W. and S. 9° E. It is a notable fact that this latter locality was simply a few square feet of surface on the same level surface with many square rods of limestone which, though covered with till, showed no signs of smoothing or striation. On the north side of the valley a mile away another slight trace of striæ was found, indicating motion toward S. 88° W. South of Plattsmouth a considerable surface of the limestone, about 40 feet above the river, is planed with striæ from east of north.

Upon the limestone ledges 3 or 4 miles south of Pacific Junction, Iowa, striæ are found at localities differing about 50 feet in elevation. They are mainly of two sets, S. 9° E. and S. 40° E. Meek, in Hayden's Final Report on Nebraska (p. 92), records near the mouth of the Platte S. 10° W. [mag.]. Dr. White in his Iowa report, Vol. I, p. 94, mentions a locality opposite Council Bluffs, now obliterated, 6 to 8 feet above high water, where the direction was S. 41° W. Prof. S. Aughey, former State geologist of Nebraska, reported striæ near Beatrice, Roca, and Syracuse, also along the Platte at several points, which have an average direction of S. 19° E. In a quarry south of Unadilla, Nebraska, though no striæ were found, the different blocks in the upper layer were tipped down toward the north without being apparently moved from their position. Two miles northeast of Tabor, Iowa, planation was widely shown, but the stone is now removed and the direction has not been ascertained.

DISTRIBUTION OF THE DRIFT.

For convenience under this topic, we will divide the drift into Nebraska, Dakota, and Iowa divisions.

THE DRIFT IN NEBRASKA.

South of Niobrara, Nebraska, at an elevation of over 400 feet above the Missouri, is an extensive exposure of clayey gravel capping the hills. This seems to be from 15 to 25 feet in thickness and to rest upon light-colored clay. Farther south the loess appears above it, and bowlders abound in it, especially in its upper portion. East of the Bazile there is the same general appearance, but below fine sand begins to show itself in the sides of the bluffs.

Volcanic ash stratum.—Underneath the drift a layer of grayish-white volcanic ashes begins to show itself 5 or 6 miles southwest of Santee Agency and is exposed here and there for at least 6 miles eastward. The localities noted are SW. $\frac{1}{4}$ secs. 27 and 35, T. 33 N., R. 4 W. At the former place it is underlain by a stratum of laminated clay crowded with fresh-water shells. Prof. R. E. Call has determined them to be mostly *Limnophysa decidiosa*. This stratum has been observed to be more than 3 feet thick. The ash seems to pass both laterally and above into a whitish marl. Both are 450 to 475 feet above the Missouri River.

Mr. Andreas Lundteigen, chemist for the Yankton Cement Works, who was interested in the deposit from a business standpoint, has kindly given me the following analysis of a sample taken from the top of the former bed on Mr. Wakana's land: Silica, 72.44 per cent; lime, 0.55 per cent; alumina and oxide of iron, 14.78 per cent; loss by ignition, 4.28 per cent; total, 92.05 per cent. A sample from the bottom did not differ materially.

A stratum exactly similar in composition has been found near West Point (Pl. XI), on the West Blue southwest of Milford, and also along the Missouri about 7 miles north of Omaha, Nebraska (Pl. XII). At all points it occurs in the drift, not below it. At West Point it is found from 4 to 6 feet thick, at the second point 1 to 5 feet, and near Omaha 18 inches. Specimens were submitted to Mr. J. S. Diller, of the Geological Survey, who has pronounced them volcanic dust, composed chiefly (90 per cent) of minute angular fragments of pumiceous glass. Besides these are numerous (10 per cent) grains of quartz sand, well rounded, indicating that the ashes fell into quite water.

If, as seems not improbable, these different beds were deposited simultaneously, how may we account for their being below the drift in Knox County and in the drift in Cuming and Seward counties? By reference to a list of elevations further on we find the altitude to be now in the first case over 1,600 feet, and in the other less than 1,500, the second being less than 1,350 feet. Even making liberal allowance for changes of level since their deposition, we can readily believe that the deposition of drift, assuming its subaqueous origin, began at the lower levels before the volcanic outburst, and did not reach the northern localities till later. The apparent haphazard occurrence of the ashes in Knox County may be readily explained by their preservation only in lagoons along the ancient Niobrara. When they fell on the land rains would soon wash them away, and when in the main stream they would be swept onward and mixed with other sediments. The idea that they fell in ponds is further supported by the occurrence of the fossiliferous clay immediately below.

If we accept the more commonly received hypothesis that the till is the product of land ice, we may suppose that the older ice sheet advanced to the altitude of West Point from the Des Moines Valley, while the occupation of the Dakota Valley was later. Or we may sup-



NEAR VIEW OF VOLCANIC ASH STRATUM IN BLUFF ABOVE WEST POINT, NEBRASKA.

pose that the deposits were simply formed in bayous along the adjacent streams when they were flowing at high levels. It should not be forgotten, however, that it is by no means certain that the ash beds in different localities were deposited at the same time.

There is little loess upon the surface of the drift for several miles east of the Bazile, and erosion has cut this bed of gravel into abrupt knolls, which are very conspicuous. Near the Bazile and along How Creek erosion has also sapped the sandy formation so that the gravel-topped knobs have sunk bodily toward the streams.

Farther east, about 5 miles southeast of Santee Agency, the loess begins to so cover the drift that it is almost entirely hidden, except along the face of the bluffs toward the Missouri. Its continued gravelly character is well shown southwest of Herrick, about what is called the Devils Nest, a descriptive name for two or three very deep ravines excavated through the loess, drift, and Tertiary sands to a depth of over 100 feet. One of the most complete sections found is at or near the northwest corner of T. 32 N., R. 3 W. The whole section, from the summit of an adjacent hill, is as follows:

Section near the northwest corner of T. 32 N., R. 3 W.

	Feet.	In.
Slope, probably loess, though boulders were found near the summit....	50	0
Loess exposed	4	0
Stratified sand, gravel, and boulderets of granite, greenstone, etc.....	0	8-18
Reddish, loamy, joint clay containing northern pebbles.....	15	0
Fine white sand, stratified	7	0
Reddish clay and rusty sand	4	0
Stratified lead colored clay	14	2
Fine sand	15	0
Wet efflorescent clay	0	8-10
Sand	4	0
Clayey sand	3-4	0
Whitish marl alternating with layers of sand.....	50	0

In another section several rods west, below the loess, which was about on a level with a corresponding point in the preceding section, the strata were as follows:

Section several rods west of the preceding.

	Feet.	In.
Stratified gravel and boulders, about four coarse layers with fine sand alternating, all sorts of northern erratics present.....	44	0
Laminated loamy clay with two layers of pebbles	3	0
Fine gray sand passing into 2 feet of chalky clay.....	16	0
Grayish checky clay, stratified, with fossil planorbis and other fresh-water shells, and a few small pebbles.....	3	0
Sand containing fragments of chalkstone and of large bones and teeth.....	1	0
Chalky clay	6	0

A general section showing several exposures noted is given in fig. 16.

The gravelly drift is also made prominent by its capping long spurs extending northward along the northern edge of the loess table-land.



BLUFF ABOVE FLORENCE, NEBRASKA, SHOWING ASH STRATUM.

miles south of Hartington, comes from the underlying sand, as does also a magnificent spring 4 miles west of Coleridge.

The sand below the drift, which is there nearly pure coarse stratified gravel, is finely shown in a cut $2\frac{1}{2}$ miles north of Coleridge. It is pure and stratified in thin layers (Pl. XIII).

In a cut near Hartington, Nebraska, the drift was found resting upon a calcareous marl much resembling loess, and differing from it principally in its more distinctly stratified character. It furnished numerous specimens of fresh-water shells, which Prof. R. E. Call, to whom they have been submitted, has identified as follows:

Valvata tricarinata Say.

Succinea obliqua Say.

Gyraulus parvus Say.

Sphaerium striatinum Lam.

Limnophysa decidiosa Say.

Limnophysa palustris [?], imperfect specimen.

Two or 3 miles east of Hartington a similar exposure was noticed in the bank of the East Bow. It seems probable that this is a late Tertiary deposit, probably belonging to the Equus beds of Cope.

The gravelly character of the drift continues south along its western limit as far at least as Creighton. East of that place, at an elevation of about 110 feet above the station, abundant traces of gravel are found by the roadside through a vertical distance of about 10 feet, above which the loess begins to appear. About $5\frac{1}{2}$ miles east of Creighton a well freshly bored was noticed at the place of Mr. D. C. Cleveland, who kindly gave me several facts, not only in regard to his own well but in regard to those in the vicinity. This well was on the general level, 150 feet above Creighton, or 1,767 above the sea. A section of the well was nearly as follows: Seventy or 75 feet of loess-like clay with no pebbles above but with numerous calcareous concretions, a few pebbles below, passing into pure gravel, which extended down to a depth of 80 feet. Below the gravel was 10 feet of fine sand. This, he told me, was the common experience in wells of that vicinity. He had the impression that water was found nearly upon a level. A well half a mile west, starting about 30 feet lower, is about 125 or 130 feet deep and has 22 feet of water. In it there was only about 40 feet of the loess-like clay. In digging wells blue clay is not usually found, but in a well about 2 miles southeast, in a valley, 2 or 3 feet of blue clay was found above sand. Whether the blue clay contained pebbles or not he was unable to say. A well bored half a mile south, 100 feet deep, was nearly or quite all in sand. A northwest-southeast line passing about half a mile south of his place marks the northern boundary of a sandy region—the ancient channel passing by Creighton and Plainview to the north branch of the Elkhorn. This line seems part of the eastern boundary of the region supplied with water from the Pliocene sands. No further trace of drift was found till we came to the upper branches of the Bow in the southern part of T. 33 N., R. 1 W., where

the drift appears again as a gravelly terrace in the sides of the principal valleys. An old resident of the region remarked that the bowlders were mostly upon the surface. This was found to agree with our observations. Because of the unusual variations of the barometer the elevation of the drift at this point was not well determined, but from its relation to the general level of the country we judge it somewhat lower than near Creighton. About Hartington and Coleridge beds of gravel and bowlders appear up to an altitude of about 1,760 feet. This elevation was noticed in the sides of the valley near Coleridge. The elevation in a high range of hills 4 miles southwest of it rises to about 1,625 feet. In the wells about Hartington, according to the testimony of Mr. Reed, a well digger of the place, the wells are from 36 to 50 feet in depth, those upon the lower land being shallower. The water is found apparently upon a level. After passing through soil and several feet of silt and alluvium (this I judge to be the case from a railroad cut near town) white clay in layers is struck and below that plastering sand with pebbles in which specimens of petrified wood are frequently found. At Coleridge, as stated by Mr. Miller, of that place, wells are 35 to 40 feet in depth, passing through about 6 feet of black soil, 17 feet of clay of loess-like character, 3 feet of sand, and then clay again.

At Concord there is 4 feet of soil, then sand without the clay. Passing eastward from Coleridge, bowlders and pebbles are found to the eastern edge of the valley upon the terrace-like tables in the valley before described, underneath the capping of silt, but after leaving the valley no pebbles are seen until the valley of the East Bow is crossed. They then appear upon a few hillsides about the same distance below the highest hilltops as before. No more drift is noticed until we reach the Missouri at Ponca. Everything is covered with loess, which in the valleys has washed down or crept down from its original higher position. In the bluffs south of Vermilion the following section was observed:

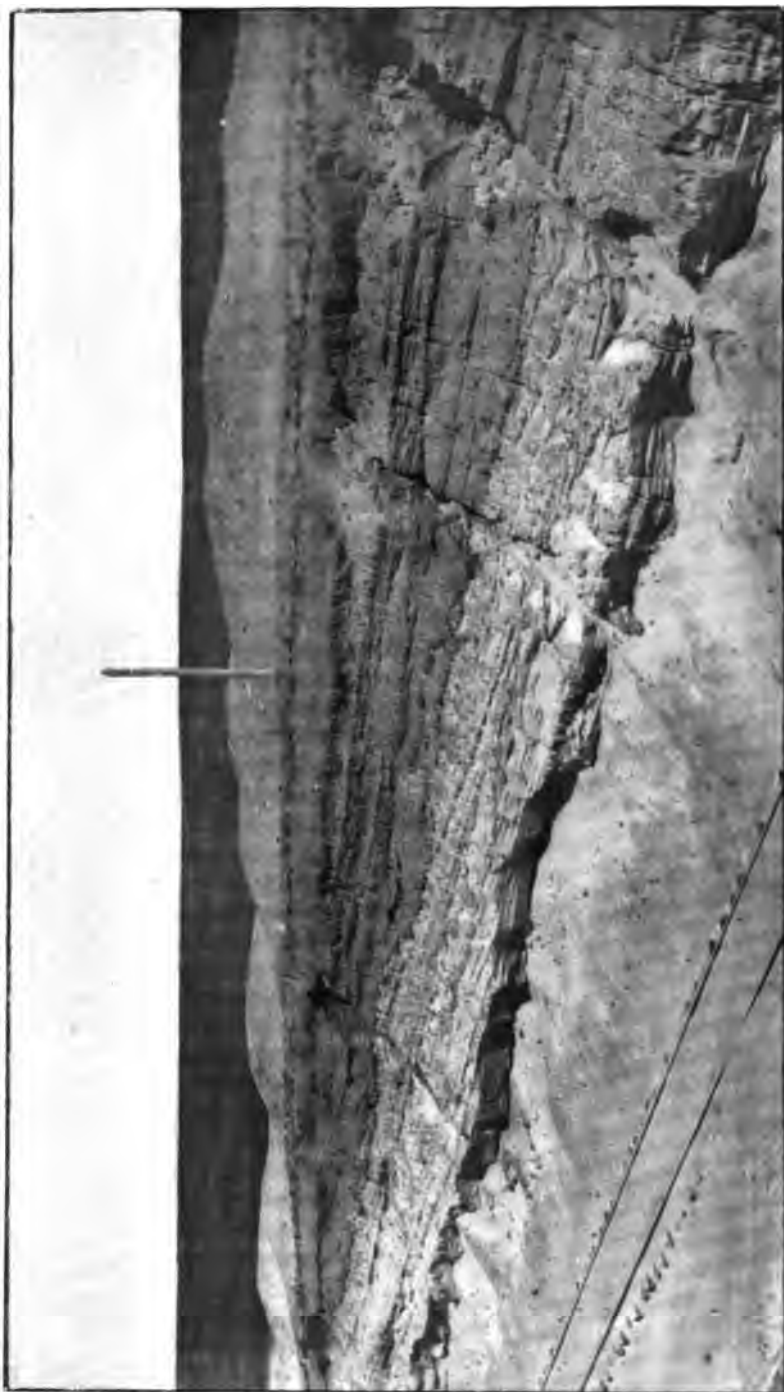
Section of the bluffs south of Vermilion, South Dakota.

Loess with a clayey stratum about 10 feet above its base, and below a few layers of small pebbles interspersed, the base itself a distinct horizontal line..	Feet. 40-50
Bowlders and stratified gravel with clayey patches.....	3-4
Coarse orange-colored sand, light above, with reddish streaks.....	3-4
Fine white sand with yellowish streaks	5-6
Cretaceous clays of the Benton group.....	95
Level of the Missouri.	

At the landing at Ponca another fine exposure was found, for which we had time to make only a hasty estimate, as follows:

Section at the landing at Ponca, Nebraska.

	Feet.	In.
Loess with several feet of sand below.....	50	0
"Chalk rock," exposed.....	10	0
"Chalk rock," not clearly exposed.....	40	0
Dark shale.....	10	0
Dark shale or hard clay with yellow layers.....	4	0
Coal.....		8-10
Rusty sandstone	4	0



BASE OF DRIFT NEAR COLERIDGE, NEBRASKA.

Along the Missouri, south of Ponca, drift exposures are not prominent. The older formations rise high and are capped with high bluffs of loess. Southwest along the railroad in Dakota County the cuts exposing drift in any form are scarcely noticeable. Clusters of boulders are reported along the valley of Elk Creek. Near Wakefield a few boulderets and northern pebbles are sometimes struck in deep wells, but generally south of the watershed bounding the immediate valley of the Missouri—that is, including the short streams flowing directly toward it—the whole surface of the country is so deeply buried with loess that northern erratics are almost unknown. Even experienced well diggers will sometimes aver that none are to be found.

More recently the opening of the Pacific Short Line from Sioux City to O'Neil, Nebraska, has afforded much better opportunities for

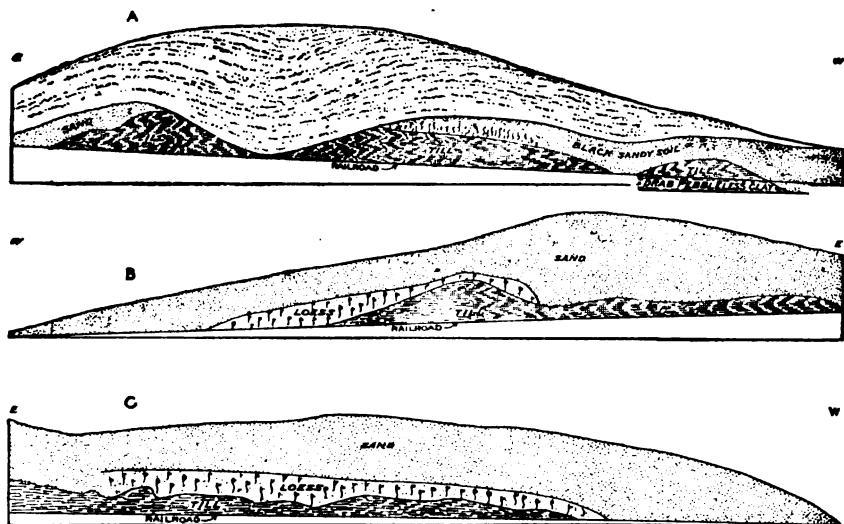


FIG. 17.—First railroad cut east of Osmond, Nebraska. Scale same as on fig. 18.

examining the surface formations of this region. It is particularly instructive between Randolph and Osmond, where it crosses the divide between the west branch of the Logan and the north branch of the Elkhorn. West of Osmond no traces of northern erratics are found except a few pebbles, which are likely to have washed from the hills immediately east. The universal subsoil is sand, which for the most part shows the shaping action of the wind. It occasionally contains grains as large as one-fourth inch long, usually of a light feldspar. In the valleys pebbles, mostly of quartz of different colors and well rounded, and unlike those commonly found in the drift, are found.

The valley of the North Elkhorn, in which Osmond lies, is bounded on the east by hills more abrupt and higher than those on the west, and boulders appear on their sides. The difference in altitude is doubtless due to erosion which has taken place since the deposition of

the drift. About 1 mile east of Osmond, and about 25 feet higher than the station, an exposure at the foot of a north slope showed typical yellow till with few pebbles, resting conformably upon a drab pebbleless clay at least 2 feet thick and exposed for 2 rods. The junction was even, horizontal, and abrupt. One passed completely into the other in less than 6 inches. The relations are shown in figs. 17 and 18. As the road rose along the east side of the valley the exposures of yellow till were found appearing regularly, usually with the upper surface rounded similar to the present surface, but not always corresponding, sometimes showing no correspondence. It is overlain by sand, loess, red loamy clay, or gray till, without trace of an old soil or distinct weathering. The ashy colors may perhaps indicate action of vegetation near water level, or in some cases more likely more direct derivation from the drab Cretaceous clays. The annexed figures show the relations of surfaces of the different formations.

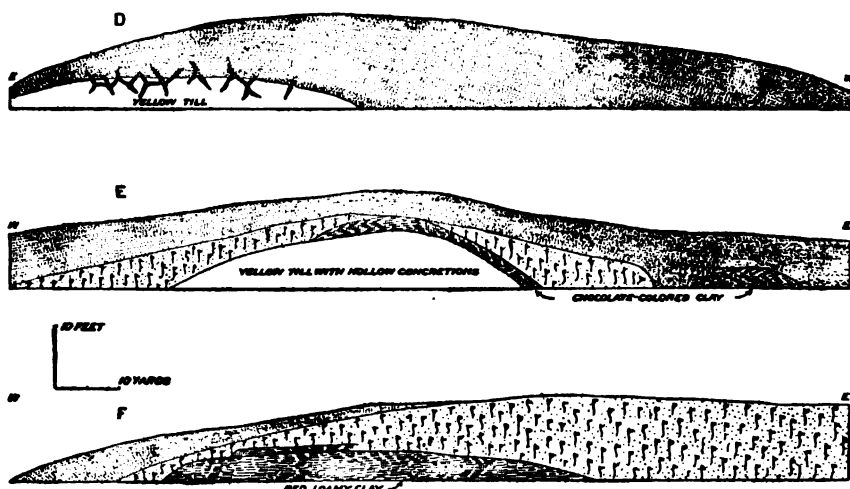


FIG. 18.—Cuts east of Osmond, Nebraska.

About 150 feet above Osmond, on the west slope of the divide, a flat area covering perhaps a square mile was noticed. From the cuts along its west and north sides it seemed to be underlain by till and topped with 20 to 30 feet of loess and sand. These last seem to intermingle indiscriminately. In some places they are interstratified. The adjoining figures sufficiently illustrate their relations. The higher ridges, rising 50 to 75 feet higher than this flat, are probably composed entirely of these materials. They usually extend northwest to southeast.

Besides the formations already mentioned there is also found a chocolate-colored variety of the reddish loam, which is darker than the usual shade of the loam. It is usually found in patches upon the latter at higher levels. The gray, pebbly clay which was noted nearly filling one of the cuts on the west side of the till flat also shows more of a chocolate shade above.

One very remarkable feature of the clays shown at higher levels, in places very conspicuously, is the occurrence of great cracks like ordinary mud cracks in their general features and arrangement, but on a vastly larger scale. They are frequently 8 to 12 inches wide at the surface of the clay and penetrate it 4 to 6 feet. They are filled with sand from the deposit above. The sand in the cracks and that directly above them for 2 or 3 feet is unstratified, while the surrounding sand is distinctly and horizontally stratified. The sand is not in the least mixed with the clay in the sides of the cracks. The cracks penetrate yellow and chocolate or gray clays alike.

Several inferences may be fairly drawn from these phenomena: (1) The till was very wet when first exposed to the air; (2) it became very dry before the advent of the sand; (3) the chocolate clays and yellow clays were deposited about the same time as the clay and have passed through similar circumstances; (4) we could not well imagine stronger proof of the subærial deposition of the sand. Its horizontally stratified character does not indicate deposition in water.

Very limited exposures of pebbly clay have been found, however, about 12 miles north of Winside, and as far southeast, along Humbug Creek; also at a few points along the north branch of the Elkhorn, which have been mentioned elsewhere. Boulders have been reported also as found along Plum Creek and Rock Creek, in Cuming County. Four or 5 miles northwest of West Point are two bends in the Elkhorn which cut deeply into its western bank. The upper one is the more complete. It displays the formation from the general level of the country down to the level of the stream, as follows:

Section on the Elkhorn 4 or 5 miles northwest of West Point, Nebraska.

	Feet.	In.
Loess, its lower surface horizontal and distinct; just above it 3 or 4 feet of compact clayey layer, with a stratum in its upper portion about 8 inches thick blotched with blackish, doubtless due to carbonaceous matter.....	50	0
Red clay, its upper half more loamy, homogeneous and without pebbles. The first 6 feet above its base presents four horizontal bands of checky clay 8 to 10 inches thick, and the next 6 feet above four more thin ones of similar character. These all alternate with sandy or loamy layers. Pebbles of red quartzite are occasionally found in thin, short layers, which occur as high as 20 feet from the base.....	45	0
Whitish clay.....	4	0
White clay or marl.....	2	0

These last two pass laterally into a stratum of volcanic ashes a few rods farther west, away from the river. This volcanic ash bed is horizontally stratified in very thin layers, its texture as fine as flour; its color, for the most part grayish white with yellowish streaks in its upper portion.

Muddy sand, passing laterally into obliquely stratified sand with boulders below.....	2½	0
Fine greenish clay, thicker at some points.....	6	
Yellow till.....	4	0
Compact blue till.....	5	0
Level of the river.		

In the lower bend the top of the till is scarcely exposed above the surface of the water. No distinct trace of the ash stratum has been found there, and the horizontal base of the loess, which is very distinctly exposed, showing above the carbonaceous layer, is only about 50 feet above the stream.

At the town of West Point, in a deep clay pit near the summit of a hill northeast of town, a combined section is as follows:

Combined section at West Point, Nebraska.

	Feet.
Loess, sandy above, showing wind-drift structure	30
Dark carbonaceous clay with numerous fragments of shrubs and roots in its upper portion	3-4
Reddish joint clay without pebbles, yellow and laminated above	4-5

On the hillside west, 40 to 50 feet below the bottom of the pit, drift pebbles are scattered.

Perhaps 15 feet lower on the hillside, by the schoolhouse, is an exposure showing about 15 feet reddish and yellow till, with a few boulders. The western side of its lower portion slopes abruptly and is overlain for several feet by horizontally stratified sand, which probably corresponds to the sand in the lower part of the high terrace along the Elkhorn farther south. The bottom of this exposure is estimated to be about 30 feet above the railroad, or 45 feet above the Elkhorn.

Where the railroad crosses the west branch of Maple Creek, in the northern part of Colfax County, the following section is exposed:

Section in Colfax County, Nebraska.

	Feet.
Loess surrounding a core of yellow till which is 15 feet in height above the bottom of the cut. This above contains many chalky seams, and exhibits reddish clay and sand upon its slope.....	25
Eight feet lower the base of the yellow till is exposed in the side of a bank near by and below it.	
Drab-colored pebbly clay and fine stratified sand	2
Clay	1½
Fine stratified sand	3

Between Tekamah and Oakland various cuts along the railroad expose the loess, "old soil," as its dark lower portion is frequently called, and red clay down to the till.

About a mile above Florence a fine section reaching down to the surface of the Missouri may be made by combining two great exposures which are not far apart. From the top of the till west it is as follows:

Section of bluff near Florence, Nebraska.

	Feet.
Timbered slope	50
Loess exposed, lower half considerably darker than above. No dark stratum near base and red clay lacking	35
Till, yellow above, but mostly blue. In a few places small pockets, containing stratified gravel and a few large ones below filled with very fine yellow compact massive sand	75
Level of the river.	

About a half mile north of the last a very different section was finely exposed by excavating for gravel at the time of the building of the Omaha waterworks near Florence. The following is the section (see Pl. XII):

Section half mile north of the last.

	Feet.
Slope	10-20
Loess	25-30
Stratified clayey loam, yellow, with many calcareous concretions	7
Volcanic dust like that found farther west, except stained with rust	1½
Yellow clayey loam, slightly stratified	5
Fine gray sand	½
Coarse sand and pebbles obliquely stratified, mostly of northern origin	20
Unexposed, probably part blue till, judging from sections on the opposite side of the river	15-20
Level of water in the Missouri.	

From many sections found along the Platte west of Fremont the following is chosen as probably the most instructive. It is found near the southern end of the old bridge southwest from town.

Section west of Fremont, Nebraska.

	Feet.	In.
Loess, the dark line 3 feet above its base appearing only as thin wavy streaks	30	0
Red clay, passing into drab and rusty below	11	0
Whitish clay with many chalky concretions and numerous pebbles, some of them scratched. This deposit ends abruptly at one end and at the other tapers out	2	0
Similar reddish and drab clay with pebbles, but with few if any bowlders ..	22	0
Light greenish clay, blotched with white, extending horizontally at least a rod. Its ends are hidden	1	2
Reddish clay, passing below into 20 feet till which is yellowish above, but the blue color rises in places near the top	11	0
Level of the river.		

Farther east, near the present bridge, a layer of coarse sand obliquely stratified replaces the blue till to the height of 10 or 12 feet above the river. This is probably a portion of the sandy substratum found in the high terrace developed along the north side of the Platte. Farther west, southeast of Timberville, the strata are the same as before given, except that the till is not exposed and the base of the till is 30 feet higher, and between it and the red clay is a stratum of blackish mucky clay 4½ feet thick. In the bluffs south of Linwood bowlders and pebbles abound at a level lying between 50 and 115 feet above the valley to the north. At the lower level several feet of fine stratified sand appears and probably rises considerably higher. Northwest of Schuyler, on the slope of a high bluff overlooking Shell Creek and the Platte Valley, many northern pebbles are found at the height of 175 to 225 feet above the latter. Bowlders abound upon the hillsides in a strip from 10 to 12 miles wide, extending along the western side of Saunders and Lancaster counties nearly to the southwest corner of the latter.

In the railroad cuts between Denton and Berks, southeast of Lincoln,

there are abundant exposures of the drift. About 3 miles east of the latter station the following section is found:

Section southeast of Berks, Nebraska.

	Feet.
Slope from the top of one of the highest hills, which was strewn abundantly with bowlders, to the edge of a deep cut	70
Yellow till, mostly exposed, with a few bowlders	30
A few rods southwest of this, in another cut overlapping, is found—	
Fine sand obliquely stratified	15

The yellow till shows obscure traces of stratification in its lower portion in the form of layers of pebbles, and banded arrangements of colors parallel with its lower surface. The sand, on the other hand, bears marks of erosion. Its strata end abruptly against the till, but no trace of distortion in them was discovered. Their eroded surface slopes abruptly toward the east. In lower cuts on the east the fine sand occurs under the drift, sometimes with greenish clay interstratified with its upper layer (see fig. 15).

About 3 miles south of Pleasant Hill, about 20 feet below the general level, the recent digging of a well furnished unusually favorable opportunity for obtaining the following section:

Section near Pleasant Hill, Nebraska.

	Feet.
Black soil	2½
Yellowish clay, passing into the next	6
Reddish clay	6
Lighter clay, distinctly separated from, but conformable with, the next	22
Fine stratified sand, quite compact. Two red quartzite bowlders were found on its upper surface	6
Sand interstratified with clayey layers	8
Niobrara chalkstone.	

Numerous small bowlders of red quartzite, greenstone, etc., are found in the deeper ravines in that vicinity on the same level with their occurrence in the well. The chalkstone also crops out farther east along Turkey Creek, and underneath it is said to occur a dark carbonaceous layer, probably of the Benton group.

About 8 miles southwest of Milford, in a deep bend in the West Blue, which cuts into its southern bank, the following interesting section¹ was found:

Section 8 miles southwest of Milford, Nebraska.

	Feet.
Soil	2
Red gritty loam	6
Stratified loamy clay with thin strata, rounded white quartz pebbles, passing into the next	9
Clayey gravel, with a few bowlders of red quartzite, passing into the next	3
Stratified loamy clay, with streaks of pebbles	15
Light-gray siliceous earth, volcanic ashes very evenly laminated	4½

¹ This section was published in *Science*, 1887.

Section 8 miles southwest of Milford, Nebraska—Continued.

	Feet.
Clay, darker above, below passing into the next.....	1½
Gray sand, with thin sheets of clay 6 to 12 inches apart.....	5
Coarse sand, with pebbles and bowlders of various sorts resting upon an uneven surface below.....	1
Hard greenish joint clay.....	6
Slope.....	8
Water of the West Blue.	

A few rods distant a less complete but similar section shows the volcanic ash layer 5 feet thick, and it appears along the sides of a ravine for several rods.

The deeper draws west of the Big Blue, in southern Seward County, frequently show beds of gravel corresponding to the upper portion of this section in which the pebbles are mostly, if not entirely, of western origin. Incomplete exposures of drift exhibiting weathered till are found in favorable circumstances over most of the region east of the bowldery strip outlined above, but the deep deposit of loess renders their occurrence quite infrequent. Near the Missouri, and at some points quite remote, the loess is found to rest upon the older rocks without traces of drift between.

THE DRIFT IN SOUTH DAKOTA.

In South Dakota there is a limited area outside the moraine which is occupied with loess. We proceed to consider the drift underneath it.

At Vermilion there is a terrace which rises about 80 feet above the flood plain of the Missouri. The southern edge of this terrace extends nearly due east from this place to Brule Creek. The structure of the terrace is unusually well shown in cuts at Vermilion. The mass of it is composed of a pebbly clay, the upper portion of which is quite homogeneous and of a yellowish color. In this were noticed certain levels several feet apart, in which bowlders were more abundant. Below the pebble clay is less homogeneous, showing pockets of sand, some stratified obliquely. The prevalent color of the whole is blue. No exposures were found lower than 20 feet above the river. Wells in the town show gravel 125 to 160 feet below the surface. The upper surface of the pebble clay was evidently eroded before the mantle of loess which covers it was put on. This loess is not considered of the same age as the more extensive deposit, but is probably simply a deposit of silt in comparatively recent times. Upon this terrace are frequently found basins resembling those upon till. The upper plain of this terrace surface extends north to the moraine and east to Brule Creek at a very uniform level. The exposures along the Vermilion River indicate that the same general characters prevail throughout.

A study of the cuts along the railroad between Beresford and Calliope indicates that the drift here, instead of being gravelly, as in northern Nebraska, is for the most part clayey, the stony ingredients, including sand, forming perhaps less than 30 per cent. Between the

moraine and Brule Creek, in shallow cuts, yellow pebble clay and loess-like clay are interstratified, perhaps by wash from loess exposures above. In the cuts near the side of the long north-south valleys running into Brule Creek from the north the pebble clay below shows a washed surface, and sometimes a thin layer of gravel, while sand prevails in the end of the cut toward the valley. Everywhere at low levels (and there are no deep cuts very high above the bottom of the valleys) the correspondence of the drift with the present surface of the country is clearly seen. In the summit cut, between Alcester and Calliope, there are exposed loess and an irregular layer of reddish clay lying above the yellow pebble clay which in some places show 5 feet or more. A few small yellow sand pockets were observed with stratified gravel in their upper portions. This was at an altitude of 90 feet above Alcester. In a cut about 25 feet in depth 2 miles west of Calliope, on the south side of the valley of a small stream and about 100 feet above the Big Sioux, the pebble clay was exposed to such depth as to exhibit a decided bluish cast in its lower portion, although the upper 15 or 20 feet showed the usual yellowish appearance. As in the cuts near Vermilion, the yellow passes insensibly into the bluish pebble clay. Here the yellow banded seams, dividing the blue till into polyhedral masses, were finely shown. Another peculiar feature of the pebble clay in this cut was the existence of cracks which resemble immense mud cracks, descending 3 or 4 feet from the surface and widening above to 4 or 5 inches. These cracks were filled with a coarse yellow sand. With this exception no deposits of sand were found in the cut. Similar cracks were found to be more numerous in some of the cuts farther west. In this same cut the pebble clay was capped with loess, an eroded surface with several inches of gravel and occasional bowlders separating them. Another feature was well shown in this cut which occurs not infrequently elsewhere, especially at lower levels in the till. These were patches of lead-colored clay, free from pebbles and resembling the Cretaceous clay in texture and color. These are often 2 or 3 feet thick and from 4 to 5 feet to a rod in width. The most rational explanation that has presented itself is that the core of the hill is of such clay, and that while the pebble clay was forming this became mixed, either en masse by the thrust of ice or by becoming plastic it flowed down on the already deposited drift. Different cases may have been formed in these different ways.

Near the Big Sioux west of Calliope the bottom of the drift, as marked by an exposure of travertine rock, is about 65 feet above the stream, while its top is 125 feet, and has the appearance of the edge of a terrace. Farther north, west of Eden, the top of the drift near the Big Sioux is about 160 feet above the Big Sioux. Along the Big Sioux north of Eden is a high terrace of stratified gravel about 65 feet above the Big Sioux, and in a slide just west the Tertiary (?) deposits, composed of lead-colored shale and sand, rise about 50 feet, above which

comes first about 4 feet of fine sand, then pebbles and bowlders. The drift continues from that upward to 117 feet upon a spur extending from higher land farther west.

Along the Dakota side of the Big Sioux below Beloit, Iowa, pre-Glacial deposits are found finely exposed at several points. They are especially conspicuous where the stream has encroached upon the highland in close proximity to the moraine. Since the formation of the bowldery terrace which slopes down from the plain about Canton to the mouth of Rock River, the stream has found the pre-Glacial beds so easily corraded that it has slipped off from the terrace and cut down from 70 to 80 feet below it.

On or near sec. 18, T. 97, R. 48, the Big Sioux has encroached upon an unusually high bank on the south. About 250 feet above the stream is a terrace corresponding in height to the upland east of Beloit, but not so high by 50 feet as the till surface a mile or two west, which we consider a part of the moraine. The terrace is not fully exposed, and in some places the slidden bank makes the thickness of strata somewhat doubtful. Beginning at the top of this terrace, we have made out a section as follows:

Section on the Big Sioux River, 3½ miles east of Fairview, South Dakota.

	Feet.
Loess.....	6-10
Till with irregular stratified sand strata toward the bottom. The lower 20 feet is blue and almost free from pebbles. Possibly equivalent to the pebbleless clay east of Canton and Sioux Falls	100-110
Fine sand with large rusty concretions of upper portions and a few fragments of large pearly shells (Unios?). This stratum is of undetermined thickness and is doubtless a source of the very copious springs along the base of the bluff farther east which deposit travertine.....	20
Unexposed. Probably much of it is a pebbleless clay of Cretaceous age....	110
Level of the Big Sioux, about 1,200 feet above the sea.	

Half a mile farther east is exposed 5 to 6 feet of black clay capped with a layer of shaly sandstone which passes below the water of the Big Sioux, forming slight rapids. This dark clay resembles closely the Benton clay as seen opposite Vermilion, but no fossils were found to decide the point. It is probably a rearrangement of this clay, or possibly a portion of the original deposit itself, which has been successfully used in making ornamental brick near Fairview.

There is little doubt that the clay and sand near Eden, South Dakota, and those shown in the cuts east of Canton, also north of Sioux City, belong to the same formation with those appearing in this section. The sand may be of very late Tertiary age.

Along the Big Sioux between the falls and Brandon the drift abounds in gravel and bowlderets, the latter being largely formed of red quartzite. From near the level of the bottom lands above the falls there extends a well-marked terrace down the river, sometimes upon one side of the river and sometimes upon the other. In its upper por-

tion it is composed of gravel, which is coarse above. Extensive exposures are found along the railroad. Its height above the river 2 miles west of Brandon, according to railroad levels, is about 80 feet. Near the northwest corner of T. 101, R. 49, are high hills, composed almost entirely of gravel, forming a ridge parallel with the stream and rising in their highest portion 210 feet above it and about 20 feet higher than the gentle slope which rises from it southward toward the moraine. In this the coarser material seems to be above. An exposure about 50 feet below the summit showed coarse plastering sand.

About the town of Sioux Falls are numerous exposures, some of which are shown in figs. 22-26. In general they show in higher places thin deposits of loess, as though deposited along the stream when flowing at higher altitudes. Below this, in some places, comes yellow pebble clay, usually with the washed surface. In one case a confused mass of boulders is found at this horizon, in others a dark layer 1 to 3 feet, as though an old soil or mud bed formed in the stream. This is usually from 30 to 40 feet above the level of the Milwaukee station. In a few cases this seems to be overlain by yellow pebble clay instead of loess.

In the cuts northeast of Sioux Falls, along the line of the Illinois Central Railroad, there is an exposure of deposits similar to those noted east of Canton. They are as follows:

Section northeast of Sioux Falls, South Dakota.

	Feet.
Loose loess	5-6
Drab, checky yellowish clay. A few black siliceous pebbles, more numerous below, with some white pebbles and small boulders of red quartzite.....	6-7
Dark soil-like clay, checked with white concretions of black pebbles, some of them trap and flat	3
Similar, but lighter, containing calcareous concretions and black pebbles. Coarser boulders come in at the top horizontally. Three rotten granite boulders were found, though there were many others which were solid	5
Gravel, with numerous boulders in the upper portions.....	10-12
A drab plastic clay with few pebbles, weathering a creamy ocher (older till) ..	5-6

The top of the last stratum is very little higher than the Chicago and Northwestern station. The gravel stratum is quite variable in thickness, and the pebbly clay above shows a dark stratum of clay which has the thickness and general appearance of a soil, but in other cases is not present.

About Garretson and north for 2 or 3 miles is a small driftless area, which is of peculiar character. The bed rock is Sioux quartzite, much fissured, and traversed with channels which are 60 or more feet in depth. The Split Rock, the principal stream, seems not to have cut to the bottom of some of the old channels. Upon this rests a loess-like loam, in places passing into fine sand. Its thickness has not been determined, partly because it is not easily differentiated from the loess, which is probably of more recent date. In a careful examination of both sides of the Split Rock for $1\frac{1}{2}$ or 2 miles north of Garretson no

case of worn surface or northern erratics was found, except a very few scattered over the surface of the underlying rock, which may easily have washed from north of the area. This feature is in marked contrast with the surface of the rock a little west of the Palisades, where the loam is absent and the rock is worn and grooved by the action of the ice. The thickness of the pre-Glacial loam at Garretson has not been clearly determined, but a thin edge of clayey gravel is found overlapping the loam a little east of Garretson, and a stony deposit of northern sand and bowldery clay is observed upon the summit of several knobs which may be detached remnants of stream beds or bowldery terraces and which rise 125 or 150 feet above Garretson, which place is, by railroad level, 1,496 feet above the sea. The connection has not been traced, but it seems probable that this stony stratum corresponds with the bowldery layer at the bottom of the till east of Canton, and that it marks the level of the discharge of water along the east edge of the Dakota lobe at a time somewhat antedating the occupation of the outer moraine. If this, however, is correct, the difference in the level and the consequent rapid currents southward would account for the coarser material. This, it will be observed, would correspond to the earlier deposition of till east of Canton. A heavy gravel deposit east of Sioux Falls would correlate well with this same deposit.

In the loam capping the high terrace just east of the Big Sioux, above the falls and opposite the city of Sioux Falls, there were found in 1894 two tusks, three or four teeth, and fragments of bones of a large mammoth. The tusks were over 6 inches through at the base, and the portions remaining were over 7 feet long and much curved. This terrace rises to about 60 feet above the present stream, and was probably the flood plain of the river during the earlier occupation of the outer moraine. At a lower level large bones, supposed to be of a mastodon, were reported at an earlier date. Probably from the lower level also came the skull of a musk ox now in the museum of the University of South Dakota.

A few miles north of Clark, in Clark County, outside of the moraine, beds containing wood and fresh-water shells were struck, in digging wells, 25 to 30 feet below the surface. This is the only case which seems to correspond with the forest beds reported from eastern Iowa and Illinois, and these are not certainly known to be covered by till.

THE DRIFT IN IOWA.

In a section opposite Fairview drift was found to a height of 240 feet above the stream. The Big Sioux has there worn deeply into the highlands on the east side. An extensive slide, probably caused by a softening of the Cretaceous or Tertiary clays below, has exposed about 50 feet of pebble clay, the upper portion of which is yellow, the lower blue, exhibiting the selenite seams, with the yellow layers adjacent, like those shown in the cut west of Calliope and already described.

From a series of cuts between the Big Sioux east of Canton and Inwood, Iowa, as well as a careful study of slopes and reports from a few wells, we construct the following section:

Section on Big Sioux, east of Canton, Iowa.

	Feet.
Loess, with an undetermined thickness of till probably occupying the lower portion. From some reports as well as from the cuts it would appear that nearly or all of it was loess, but from the distribution of water and the reports of other well-diggers it seems that half or two-thirds of it is till..	90-100
Gravelly clay in places. This seems to be the same which is conspicuously developed as a shoulder along the hillsides next the Big Sioux farther west.	10-20
Pebbleless loamy clay which weathers a creamy yellow (older till?).....	50
A fine stratified sand without gravel, but no northern erratics. This sand probably corresponds to the sand west of Fairview. It is water bearing, furnishing a spring in a railroad cut.....	18-20
Unexposed, probably Cretaceous	60-75
Level of Big Sioux, 1,227 feet.	.

East of Kruger's mill, back of a terrace about 50 feet in height, the drift appears on the south side of a small stream showing a section, beginning about 108 feet above the stream, as follows:

Section east of Kruger's mill.

	Feet.
Reddish pebbly clay with some sand	9-10
Stratified sand, with sheets of clay obliquely set, and from a half inch to 6 inches thick	24
Blue till with an irregular surface above	5-6

Higher than this section the slope shows pebbles to a height of 180 feet, where boulders are more common. North of the small stream, along what appears to be a much-eroded terrace, boulders and gravel occur to the height of 125 feet, above which there is 30 feet of loess.

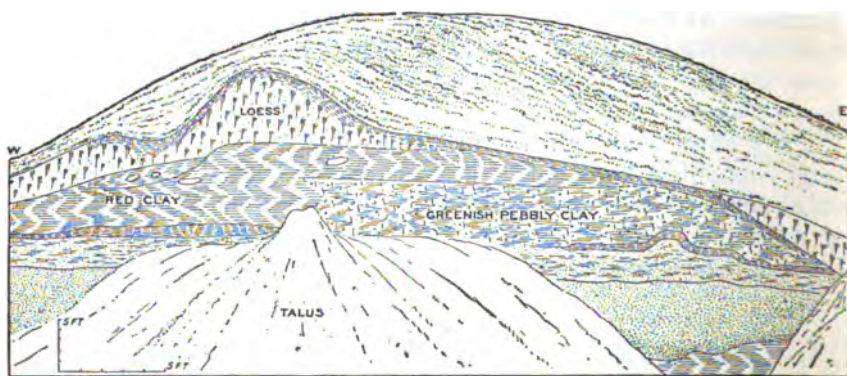


FIG. 19.—Sandpit section east of McCook, South Dakota.

Three or 4 miles west of Larchwood shallow wells show 5 to 10 feet of loess, below which comes yellow pebble clay or till. This seems to be the prevailing character of the upland region of Iowa throughout Lyon County.

Seven or 8 miles northwest of Sioux City, about St. Onge's place, as mentioned by Dr. White in his report, and not far from the ranch of D. H. Talbot, are several exposures showing the more recent deposits overlying the Cretaceous Inoceramus limestone beds, which form a conspicuous shoulder along the bluffs for many miles. The higher level of the Cretaceous is about 140 feet above the Big Sioux. Above this lies a bed of waxy yellow clay with irregular upper surface. It seems to be derived from the weathering of the limestone on which it rests. Above this is a bed of gray sand, coarser below. This has been sought for plastering purposes in Sioux City. A sketch of one exposure is shown in fig. 19. In no case have I seen more than 12 feet exposed, but it is probably much thicker farther back. The sand passes above into a greenish joint clay without pebbles. Upon this rests a thin layer of reddish till containing the usual northern erratics, and just above comes the loess. All the exposures studied indicate that the clays and loess have been let down and distorted by the escape of the sand from below. A generalized section would be as follows:

Generalized section near Sioux City, Iowa.

	Feet.
Loess.....	50
Reddish till	3-5
Greenish joint clay without pebbles.....	2-5
Gray sand, clayey above, coarser below	7-12
Yellow waxy clay.....	5-9
Cretaceous No. 3.....	140
Level of Big Sioux.	

About a mile northeast of the railroad bridge across the Big Sioux, near Riverside, are several sandpits. In one a large lenticular mass of till was found in the loess. This was described and figured in 1895.¹

One mile above Sioux City, between the summit of Dakota Point and the river, the following section may be found:

Section 1 mile above Sioux City, Iowa.

	Feet.
Slope.....	25
Loess, exposed, with several feet at base darkly covered with carbonaceous matter.....	150
Yellow till with an uneven surface above, reddish and loamy	55
Low water in the Missouri.	

About a mile farther up the river, at the base of the bluff, is an exposure of gravel about 60 yards in length and 15 to 20 feet in thickness. Its base is unexposed, but its upper surface, which is about 50 feet above the water in the Big Sioux, is a horizontal line, and the loess stratified below rests directly upon it. A remarkable feature in the gravel is the occurrence of three great bands of coarse gravel and cobblestones, alternating with finer material, which dip abruptly to the south through the whole height of the exposure. The dip above is about 18°, but gradually diminishes toward the base.

¹ Proc. Iowa Acad. Sci., Vol. II, pp. 20-23; also by H. F. Bain in Iowa Geol. Rept., Vol. V, p. 234.

A study of this locality, which is near Riverside Station, subsequent to extensive removal of the gravel revealed the following facts, some of them quite puzzling. At first view it seems a clear case of till between two beds of loess. The gravel shows a level surface for several rods, and at the south end it has been found to be at least 30 feet thick. At that depth water, probably on a level with the river, prevented further excavation. Above the gravel at the south end rises 50 to 75 feet of loess. In it were found a few shells of *Limnæa* and *Sphærium*, which have not been observed elsewhere in the loess of this region. The summit of the hill back rises about 130 feet above the river.

At the north end of the exposure and 100 yards from the last the section above the gravel is as follows:

Section near Riverside Station, Iowa.

	Feet.
Slope, loess.....	50
Loess, exposed.....	5-6
Reddish till, thinning and dropping to the south and running out in about 80 yards.....	18
Massive loess-like silt, containing <i>Succinea arara</i> , similar to those now living on the bluff back, blotched above with carbonaceous matter, with a few fragments of water plants (?).....	6
Upper surface of the gravel somewhat interstratified with the silt, and containing the same <i>Succinea</i> .	

Within a quarter of a mile farther north the top of the Cretaceous is evenly exposed about 80 feet above the river, and above it fine sand with pebbly clay above rising to 90 to 190 feet, the beds resembling those already noted near Talbot's. The most plausible explanation suggested at present is, therefore, that the gravel pit shows a comparatively recent formation in the base of a high terrace, possibly corresponding to that south of Sioux City.¹

At Missouri Valley, back of the brickyard, there is found the following section:

Section at Missouri Valley, Iowa.

	Feet.
Loess, exposed, with "charcoal streak" a few inches above the base pretty well developed for this region. This loess shows crevasses or slight cracks nearly vertical from top to bottom	90
Drift exposed mostly reddish clay, loamy above, more stony below, and passing into blue till below	40
Thirty feet above station.	

One to 1½ miles north of Council Bluffs are found three great sand pits in the side of the bluffs. They are known from their owners' names as Lawlor's, Clark's, and Cassady's sand banks, naming them in order beginning with the most northern. At Clark's bank we find the most complete exposure, although some of the members are bet-

¹ Compare also an explanation in Proc. Iowa Acad. Sci. (1895), Vol. II, pp. 20, 23.

ter represented in the other banks. The section at Clark's bank is as follows:

Section at Clark's sand bank, 1 to 1½ miles north of Council Bluffs, Iowa.

	Feet.
Loess, exposed, which is sandy below	20
Dark clayey loam	3-4
Coarse sand, obliquely stratified in thick layers, with a layer of clay 6 to 8 inches in thickness, interpolated 12 to 15 feet from the bottom	40
Gravel	5
Blue till, white pebbles	8-10
Unexposed, but probably mostly till (level of the lake)	25

At Lawlor's the sand is slightly consolidated in its upper layers, forming a sandstone a few inches thick. A row of angular blocks of clay appears in the sand 12 to 15 feet above the base. The gravel is found 8 feet thick, obliquely stratified, with layers 8 to 12 inches in thickness. The blue clay appears as before.

At Cassidy's bank, 2 or 3 miles north of Council Bluffs, Iowa, we have the following section:

Section at Cassidy's sand bank, 1 to 1½ miles north of Council Bluffs, Iowa.

	Feet.	In.
Slope	80	0
Loess, exposed	20	0
Clayey loess, with concretions	3-4	0
Sandy loess	3-4	0
Coarse sand, suitable for plastering, found in eight or nine layers 3 to 10 feet thick, all obliquely stratified, dipping toward the south, excepting one or two	45	0
Fine wet clay, uniform in thickness	1	3
Rusty, coarse sand with cobblestones below; some of the layers consolidated	10-12	0

Below the last number a copious spring comes out, which, probably like many others, marks the upper surface of the till.

From 4 to 5 miles north of Pacific Junction, along the base of the bluffs, are some remarkable exposures showing the base of the blue till. This is seen to extend horizontally for a mile or more, being exposed very distinctly. In the principal exposure the following section is found:

Section 4 miles north of Pacific Junction, Iowa.

	Feet.
Loess	15
Yellow, reddish, and loamy pebble clay	15
Slope, indicating much rusty sand	55
Consolidated sand	½
Clayey gravel in patches, with fine yellowish sand, and strips of yellow and blue till intermingled with them	12-15
Typical blue till, with its base very even and horizontal	3-5
Joint clay without pebbles, of a dark brownish gray, passing below, in its thickest portion, into reddish clay with horizontal bands of rounded concretions from 4 to 6 inches in diameter; its lowest surface very uneven	11-17
Light gray, fine, stratified sand, containing small globular concretions	9-10
Level of Missouri bottom lands.	

About 2 miles north of Pacific Junction the following section is exposed:

Section 2 miles north of Pacific Junction, Iowa.

	Feet.
Brownish clay, passing up into soil.....	3
Light-colored sandy marl, passing into marl below, and with black and white concretions above.....	3
Layer of chalky concretions with black interior.....	$\frac{1}{2}$
Very fine sand, obliquely stratified, passing abruptly below into the next....	6
Coarse sand and small quartz pebbles	4

East of Pacific Junction, in a spur of the bluffs near Keg Creek, is a deep railroad cut with the following section:

Section near Keg Creek, Iowa.

	Feet.
Loess.....	50
Dark-reddish or chocolate-colored loam extending horizontally across the exposure	3-4
Yellow till, uneven above and with loess filling the depressions under the dark stratum, many chalky concretions above and large, irregular sand pockets below. Remains of a young mammoth was found in the base of the loess or top of till	20-25
Unexposed.....	4-5
Irregularly bedded limestone, Carboniferous.....	4

At the point of the bluff south of Pacific Junction 2 or 3 miles, at one of a series of copious springs, there is the following exposure of drift:

Exposure 2 miles south of Pacific Junction, Iowa.

	Feet.
Stratified gravel, somewhat consolidated	2-6
Dark blue till, resting directly upon the next.....	$\frac{1}{2}$ -1
Gray limestone, which is striated in a direction S. 15° E. (mag.); this is about 20 feet above the bottom land	2

One-half mile farther south and 60 feet above the bottom land is another glaciated surface, several yards in extent, upon a layer of compact blue limestone about a foot thick, resting upon clay. Striæ are found upon its surface having the following directions: The deeper ones S. 18° E. and S. 26° E. There are also some S. 54° E. and S. 52° E., very distinct, and still smaller ones S. 70° E. About a rod east of the first locality striæ were found S. 14° E. and S. 8° E. There are now only a few inches of rusty sand resting on this surface, with the loess above.

In southwestern Iowa numerous exposures have been examined along the various railroads. It seems unnecessary to enter into details, but better to give only a general statement. As a rule, the loess shows four or five clayey layers, from a foot to a foot and a half in thickness at its base, with frequent traces of carbonaceous matter in its lower portion. Underneath this appears the red clay, first without and then with pebbles, passing below into till, which in some cases, as near Clarinda, is 40 feet or more thick.

The junction of the loess appears as a rule only in the higher cuts upon the summits separating the principal streams flowing into the Missouri. Lower cuts, which are the most common, present an eroded surface of till upon which the loess rests, with the red clay occasionally appearing between. Usually the surface of the drift is approximately parallel to the present surface of the country, its convexity usually being less. The till presents the same features which have been noticed elsewhere.

ELEVATIONS OF SURFACE OF DRIFT IN LOESS REGION.

These elevations, from the nature of the case, are less definite than some which have been given. For the most part they are of points where the loess and drift show their original relation to each other. They are in every case barometric. Those showing old soil or charcoal streaks are marked with an asterisk *); eroded surface under deep loess with an obelisk (†).

Elevations of surface of drift in loess region.

Locality.	Elevation above the Missouri.	Elevation above the sea.
	<i>Feet.</i>	<i>Feet.</i>
South of Niobrara.....	425-460	1, 645-1, 680
Devils Nest.....	450-475	1, 650-1, 680
East of Creighton.....	470	1, 690
East of Osmond.....	(†)	1, 700-1, 760
East of Norfolk.....	415	1, 620
Twelve miles north of Northside.....	415	1, 620
Clarkson.....	530†	1, 560
Five miles northwest of Schnyler.....	560	1, 572
Near Linwood.....	390	1, 400
Bone Creek, east of David City.....	510	1, 595
Germantown.....	575	1, 530
East of Milford.....	500	1, 450
Berks.....	530-555	1, 450-1, 475
Eight miles southwest of Milford.....	555-580	1, 475-1, 500
South of Pleasant Hill.....	560	1, 475
Four miles southeast of Yankton.....	255	1, 440
South of St. Helena.....	150	1, 320
Five miles northwest of Hartington.....	385	1, 555
Five miles southwest of Hartington.....	450	1, 610
West of Coleridge.....	590†	1, 710†
Northeast of Emerson.....	260†	1, 360†
Five miles northwest of West Point.....	380*	1, 426
Southeast of Timberville.....	330*	1, 340
Southwest of Fremont.....	270*	1, 280

Elevations of surface of drift in loess region—Continued.

Locality.	Elevation above the Missouri.	Elevation above the sea.
	<i>Feet.</i>	<i>Feet.</i>
Cheney.....	475	1,400
Bennett.....	400	1,320
West of Syracuse.....	205	1,125
East of Syracuse.....	255	1,175
West of Larchwood, Iowa.....	225†	1,465†
West of Inwood, Iowa.....	235	1,450
East of Fairview, South Dakota.....	245	1,450
West of Eden.....	220†	1,400
East of Hawarden, Iowa.....	270	1,370
Opposite Vermilion, South Dakota.....	350	1,450
Seven miles northwest of Sioux City.....	175	1,280
Riverside Park, near Sioux City.....	95	1,200
Northwest of Tekamah, Nebraska.....	290	1310
Blair, Nebraska.....	190	1200
About 4 miles northwest of Florence.....	140*	1130
One mile north of Florence.....	75	1165
North of Council Bluffs, Iowa.....	75	1065
At Council Bluffs.....	70	1055
Five miles north of Pacific Junction.....	150	1110
West of Silver City.....	170	1180
East of Pacific Junction.....	50*	1000
South of Pacific Junction.....	100	1065
West of Plattsmouth Bridge.....	100*	1055
East of Sanborn.....		1550
East of Marcus.....		1560
Northwest of Manilla.....		1475
West of Minden.....	225	1230
East of Minden.....	225	1230
West of Marne.....	335*	1350
West of Malvern.....	200	1150
Southeast of Malvern.....	125*	1075
West of Red Oak.....	185	1140
West of Valisca.....	275	1230
Southwest of Shenandoah.....	240	1154
East of Shenandoah (Page Center).....	345	1265
East of Clarinda (New Market).....	380*	1320

The elevations given from Iowa are mostly taken from the summits between important streams. The junction of the red clay and loess often lies considerably lower in the cuts adjacent to these.

RELATIONS OF DRIFT TO LOESS.

The relations of the drift to the loess vary in different localities. Prof. N. H. Winchell in his annual report for 1877 published observations indicating the gradual passage of loess into till in the southwestern part of Rock County, Minnesota. This would nearly correspond to what the writer has elsewhere described in sections where the till and loess are connected through the medium of the red clay. Where the upper surface of the latter is rendered indistinct by the absence of the "old soil" and the loamy and pebbleless character of the red clay the statement of Professor Winchell would be exactly realized. Such have been frequently found by the writer in southwestern Iowa, especially where deposits have been somewhat disintegrated by weathering or leaching. Nevertheless, that the normal relation, at least in the central portion of the region, is one of distinct division between the red clay and loess seems borne out by observations which have been recorded above. As has been found in numerous localities, the drift often has a very distinctly eroded surface, which is marked by its unevenness and by the presence upon it of an unusual number of pebbles and bowlders. This washed surface, so far as has been observed, is confined to lower elevations; in southwestern Iowa to within 100 feet above the present streams. It is uniformly found in cuts where the railroad passes through the spurs running into a valley. The surface of the drift is convex, but in less degree than that of the loess above. Another interesting relation is found in the cuts adjoining the more important streams. In such cases the drift loses, in a measure, its parallelism with the present surface or with that of the loess, and its culmination in any cut is usually toward the more important stream, as would naturally follow from the greater erosion of the loess on that side. This is found to hold true provided the important stream rises within the loess area.

THE "OLD SOIL" AND THE CHARCOAL STREAK.

Numerous references have been made to the carbonaceous matter between the loess and red clay. Where the deposits are well preserved at the junctions of these formations there is rarely an absence of carbonaceous matter. It is sometimes in the form of driftwood scattered in the clay, as in cuts southeast of Malvern, at West Point, and southeast of Timberville, Nebraska. More frequently it has the appearance of a dusky shading of the clay, usually for 3 or 4 feet just above the base of the loess. This is frequently true where the driftwood is found. The term "old soil" is properly applied to such exposures. Its color may often be well described as chocolate, though it is sometimes more like that of black loam. The carbonaceous matter is sometimes found in wavy streaks scattered through the clay, as though sparingly deposited with the embedding of the material. Angular fragments of charcoal are distributed in the same deposit, usually very sparsely, but sometimes in pockets. These fragments are generally quite minute, but

in one case they were found nearly half an inch through and apparently from sticks 6 inches in diameter. That these fragments are of charcoal rather than of rotten wood is indicated, although not proved, by their angular character, and the fact that at this same horizon wood is found well preserved. From the presence of the charcoal this has been named the charcoal streak.

The old soil and charcoal streak are found only where the surface of the drift is not eroded. In using the term "old soil" the writer would

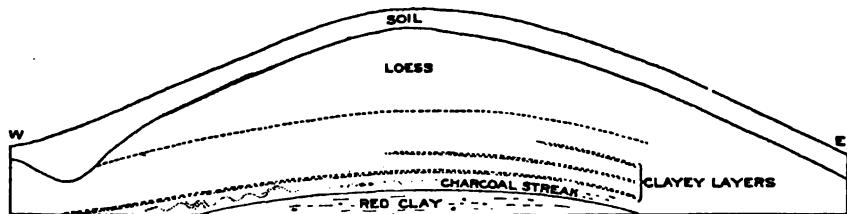


FIG. 20.—Summit cut between Silver and Keg creeks.

not assume that such is its real character. No unmistakable evidence of plants growing in position has been found in it. Although some of the fragments apparently are from roots, examination has not shown them to be in their natural position, while in other localities, as at Malvern, Iowa, the fragments have a slivered and worn appearance, as if they had been transported.

Another question arising at this point is whether this stratum is more closely connected with the loess or with the red clay. Usually the material and structure of the deposit aside from the carbonaceous matter are hardly distinguishable from the loess. Moreover, often the

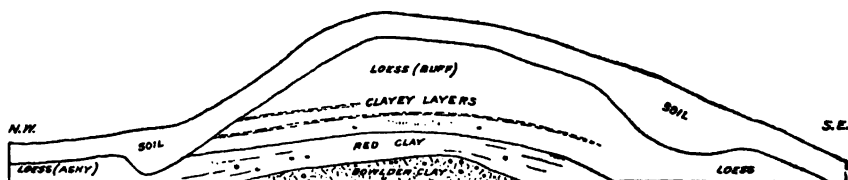


FIG. 21.—Cut on Omaha and St. Louis Railroad west of Walnut Creek, Mills County, Iowa.

junction between it and the red clay is distinctly marked, while on the other hand, although its color ends quite abruptly upward, the body of the deposit seems continuous with the loess. We conclude, therefore, that in most cases, at least in this region, the formation is a deposit of carbonaceous mud. In some localities, especially the more elevated and those toward the western margin of the region, it may prove to be real soil. Figs. 20 and 21 illustrate some of the points mentioned above.

SUMMARY.

The drift in this region is represented by three members—till, red clay, and gravel and sand beds.

The first is confined mainly, if not exclusively, to a belt along the

Big Sioux and Missouri from 30 to 50 miles wide in the northern portion, but rapidly widening below Dakota City, so that in the latitude of Lincoln it reaches from the Big Blue west of the Missouri to at least an equal distance east of that river. The second is found everywhere except where its absence can be referred to erosion. In its pebbleless form it continues westward indefinitely underneath the "old soil." The third is most extensively developed in Knox and Cedar counties, Nebraska, at a high level; but similar deposits are found near the present channels of the Big Sioux and Missouri at much lower levels, especially southward.

As to elevation, the first is mainly confined to medium and lower levels. The second is found at all levels, though more removed by erosion at lower levels. The third occurs at higher and lower levels less frequently than at medium elevations.

The drift, as was long ago recorded by Dr. C. A. White, is less prominently developed near the Missouri.

The base of the drift is found where the blue till is wanting, as in northern Nebraska, and in the lowest levels along the Missouri River in the southern part of the region under consideration; also at other locations throughout this region where older rocks protrude to unusual height. In other circumstances it is not found.

The drift of the region, so far as has been observed, contains no erratics of local origin except within 5 or 6 feet of the original beds.

Striæ are of exceptional occurrence even in localities where they are found. Disturbance of underlying beds has been very rarely observed, and where observed it is of inconsiderable amount.

LOESS.

We proceed to consider the loess, which covers this region as a mantle and, with superabundant folds, spreads farther west and south. In our discussion of its characteristics we shall find it convenient to transcend the bounds of the drift as before laid down.

By the term loess we would designate, in the present case, not simply the kind of deposit, but only the deposits of this kind which were made contemporaneously with its principal development in this region. The silt capping of the high terraces before mentioned and the bulk of some of the more recent terraces are physically indistinguishable from the true loess. The same is true of an older deposit described elsewhere.

Structure and composition of the loess.—The loess has been so often defined that a detailed description is unnecessary. It is composed mainly of fine grains of silica, some of which attain the size of 0.2 of a millimeter, though much the greater number of particles are less than 0.01 of a millimeter. These particles are coated, more or less, with oxide of iron and calcium carbonate. The amount of the former gives it its color, which in the typical form is usually a light buff. With it are

mixed many small grains of clay. The finer ingredients appear to constitute a cement which holds it firmly together, so that it usually stands firm like indurated rock, unless softened by moisture. In the latter case it has a very slow, creeping movement on slope. It is often traversed by vertical fissures, which in some cases may be compared with crevasses in glaciers. In some localities the grains of silica are rather angular, even the largest, but more commonly, so far as observation goes, the larger grains are more or less rounded, sometimes worn smooth, and the smaller grains, though relatively less worn, are apparently as much so as could be expected from their diminutive size and the consequent feebleness of their impact during transportation.

Though remarkably homogeneous, it still shows variations in color, which are often quite conspicuous when seen over extensive exposures. Its usual color is a dull yellow, but it is not infrequently of a light ashy hue, with a bluish cast when permeated with moisture. The distribution of these colors forms one of the most reliable evidences of its stratified character. In the extensive excavations recently carried on near Council Bluffs, Iowa, an obviously darker band could be seen when viewed from a distance, marking a horizontal line for half a mile or more. This was some 75 or 80 feet above the bottom lands of the Missouri. Similar horizontal bands have been traced in cuts of higher elevation and more remote from the Missouri. This obscure stratification has also been found in some cuts to show a curved arrangement corresponding to the surfaces above and below. The ashy appearance in other cases seems to be a result of more recent leaching of the loess by carbonaceous waters. In this way may be explained the frequent occurrence of ashy loess near the ends of cuts.

Extent of the loess.—The boundary of the loess on the west is very indefinitely determined, and must necessarily remain so for several reasons: (1) The obscuring of the limit by the encroachment of the sand from the west, under the influence of the wind; (2) the possible passing of loess into this sandy deposit on the west; (3) the close resemblance of the loess to residuary loams and to lacustrine and fluvial deposits of a different epoch. In general it may be said to extend along the Elkhorn, Platte, and Republican rivers indefinitely westward, while over the areas between it extends not nearly so far. As observed near Friend and Dorchester, Nebraska, the prevalent deposit is not the typical loess, but is much more clayey, and the yellowish tint is replaced by a reddish, so that it resembles a deposit found elsewhere beneath the loess. Whether this deposit is really a clayey equivalent of the loess or whether it is of older formation has not been determined. It has been observed by the writer near Norfolk and thence down the Elkhorn to its mouth; also up the Loup River as far as Scotia, and along the Platte as far as Plum Creek, and deep deposits of it are reported from the vicinity of the North Platte. It abounds, according to Professor Aughey, along the Republican.

The eastern edge of the loess is difficult to determine because the deposit is fragmentary and is deeply covered with soil closely resembling that of weathered drift. The presence of pebbles is usually, though not always, decisive proof of underlying drift, but much of the drift seems covered with a soil in which pebbles are scarce. The eastern boundary of the loess is described by Dr. White in his report upon the geology of Iowa, Vol. I, page 109, viz:

Commencing at the southeastern corner of Fremont County, follow up the watershed between the East Nishnabotany and West Tarkio rivers to the southern boundary of Cass County, thence to the center of Audubon County, thence to Tiptop (Arcadia) Station on the Chicago and Northwestern Railway, thence by a broad curve westward to the northwest corner of Plymouth County. The last-named point is probably very near the most northerly point to which the deposit reaches, certainly the most northerly one to which it reaches in Iowa.

Further investigation has shown the last statement to be an error. Moreover, the loess continues east of the limit named, becoming of lighter color, coarser texture, and less homogenous, passing in the Des Moines Valley into the second till of McGee.

According to Prof. N. H. Winchell, of the Minnesota survey, it rises to the 1,550-foot contour line in Rock and Nobles counties, Minnesota, or geographically it extends nearly to the southwest quarter of the former county and the southwest township of the latter, with a narrow area along the south boundary of the former county connecting them. In Iowa it is found covering most of the surface of Lyon and Sioux counties. This continues the boundary from the point last named by Dr. White more than 50 miles farther north.

The general statement given in the above quotation is correct, but additions may be made to it as follows: While the eastern edge in Lyon, Sioux, and Cherokee counties is ill defined, in Sac County it follows the watershed, and in Carroll and Guthrie counties the loess terminates in a thick, abrupt edge overlooking the valley of the Middle Raccoon in a way similar to that in which it overlooks the drift region west of the Big Sioux in Lincoln County, South Dakota, from the high bluffs east of the same stream. This feature was first described by Prof. O. St. John in the Iowa reports. It is well shown by figs. 23 and 24 (pp. 101, 102), taken from the same. It will be remembered that a similar relation existed along its northern edge in northern Nebraska and in northwestern Iowa.

In Adams County and adjacent counties in southwestern Iowa the loess extends up the valleys of the principal streams, while the drift occupies the higher country.

Southward the boundary of the loess has not been well determined. It certainly preserves its typical features and undoubted character along the immediate valley of the Missouri to Kansas City and beyond. Several of the Missouri geologists have recognized it in the surface clays covering most of the counties of that State north of the Missouri River.

Fossils in the loess.—Land and fresh-water shells belonging to recent species are found in great abundance in certain localities of the loess. They belong mostly to terrestrial species, but a few are distinctly aquatic. These fossils have not been noticed in northern Nebraska near the moraine, but mostly in southwestern Iowa and central Nebraska. Fragments of unios have been reported from northwestern Iowa, but they seem likely to have been derived from the graves of Indians, by whom they were used as ornaments. They may have been scattered also around camps where they were eaten. In the loess bluffs near the Missouri in southwestern Iowa patches of ash-colored loess are found connected with faint impressions, which seem to be traces of pieces of bark and driftwood, but such can not be positively stated. Some of the horizontal streaks and bands of ashy loess may mark the former deposition of vegetable matter which by its decay in its porous surroundings has reduced the sesquioxide of iron, which gives the yellow tinge to the loess, to a carbonate which has been removed. In several localities detached bones and teeth have been found 20 feet or more below the surface; but as a whole the loess is a remarkably barren deposit.

In some localities certain horizons in the loess are very rich in fossil shells over considerable areas. At Missouri Valley, Iowa, 3 or 4 feet above the horizontal junction of the loess with the red clay, numerous specimens of *Helix alternata* and *Succinea obliqua* are found with more common smaller species. The exposures exhibiting these are along the bluffs facing the valley west.

At Council Bluffs a horizon of similar shells occurs 4 or 5 feet above a dark layer resembling what has been called elsewhere the "old soil," but in this case it is found far above the base of the loess, at least 40 feet, and how much more can not be stated, as the drift is not exposed at that point.¹

Concretions in the loess.—These have been well described by Professor Call,² as well as by others earlier. A few notes concerning their distribution may be added. They abound at certain levels, within 100 feet above the present bottom lands of the Missouri, in great profusion. They are occasionally found in horizontal bands, suggesting their formation along an ancient water level. Sometimes, however, especially in greater altitudes, they appear in curved lines approximately parallel with the present surface. Such a case suggests their correspondence with the upper surface of a portion of the loess which at one time was water-soaked. Their frequent association with holes formed by roots suggests further the idea that they have been formed by the reduction of the dissolved bicarbonate of lime to the carbonate by evaporation.

¹For further and more complete statements regarding the loess fossils of this region, see S. Aughey, Hayden's annual report for 1874, pp. 266-269; R. E. Call, *Am. Nat.*, 1882, p. 380; F. B. Meek, *Geol. of Missouri*, vol. 2, p. 215 (this does not exclude fossils from the alluvium); J. E. Todd, *Proc. Am. Assoc. Adv. Sci.*, vol. 27, p. 235. B. Shimek, *Proc. Iowa Acad. Sci.*, vol. 5, p. 32.

²A paper published in *The American Naturalist*, May, 1882.

Such an explanation will not, however, explain the curiously cracked interior of the concretions. Although their calcareous character is so prominent, a little examination shows that they are largely composed of such siliceous grains as constitute the bulk of the loess. That they were not first masses of calcareous mud, perfected by concretionary action, seems evident from their position, which is usually with the longer axis vertical. Their cracked interior, rather than the result of its shrinking, as has been frequently suggested, is more probably produced by the expansion of the exterior by the building in of fresh particles from time to time between those already deposited. The age of these concretions may not be very great, for they are frequently observed in loess which has been recently rearranged.

Besides the calcareous concretions which have been considered thus far there are frequently found concretions of iron oxide. These are formed universally around decayed roots or root marks, and are sometimes elongated so as to resemble lead pencils in size and shape. Usually in their axis is an opening formerly occupied by a root.

Origin of the loess.—In comparing the loess with the extensive Oretaceous clays exposed along the Upper Missouri, and evidently forming much of the floor upon which the drift sheet of Dakota rests, one is struck with the abundance of silica in the former and the almost entire absence of it in the latter. Hence the idea that the loess is mainly the product of the grinding of the glaciers, at least so far as the Dakota lobe is concerned, seems to be erroneous. If, however, we turn to the Tertiary deposits of the plains west, we discover vast beds of very similar loams, in both the Loup Fork and the Laramie formations. There is underneath the prevailing greenish quartzite, which here and there caps the table-lands along the Ponca Reach, a deposit 10 to 20 feet thick scarcely distinguishable from the loess. Trace of apparently the same formation is mentioned by Prof. N. H. Winchell in his report on the Ludlow expedition, as found along the Cannonball.¹ It seems probable, therefore, that much of the loess material was derived from the western tributaries of the Missouri and not exclusively from the beds stirred up by the Dakota glaciers, and yet there is a probability that these sandy beds may have formerly extended into the James Valley, and so may have contributed to the loess through the instrumentality of the ice sheet. The calcareous and alkaline ingredients of the loess, on the other hand, were probably derived from the alkaline clays and chalk beds in southern South Dakota. These have given it some of its cementing constituents, which are the cause of some of its most peculiar physical properties.

Thickness of the loess.—The regularity in both the upper and the lower surfaces of the loess before mentioned is likely to mislead one in estimating its thickness. Several writers have apparently taken the distance from the summit of a hill to the highest exposure of the drift

¹ See report of Captain Ludlow's reconnaissance of the Black Hills, 1874, p. 23.

underneath this as the thickness of the loess. This may result in magnifying it two or three fold. In northwestern Iowa the railroad cuts rarely show a thickness of more than 15 feet, and more frequently less than 10 feet, and it lies from 150 to 250 feet above the Big Sioux. In southeastern South Dakota it is found in a very similar position.

In Fremont County, Iowa, its thickness, as shown by wells, is from 150 feet at a very few points near the Missouri to 40 or 50 feet near the Nishnabotany. It becomes very thin between the Nishnabotany and the Nodaway, in Page County. In southwestern Iowa it occurs down nearly to the level of the present flood plain of the Missouri. But usually in such cases there are signs of rearrangement—it has either slipped bodily from a higher position or has washed down, or else forms portion of a terrace of the Missouri at a lower level.

In northern Nebraska its thickness, so far as can be determined, is rarely over 100 feet in Knox County, and is more frequently less than 50 feet, but it is elevated from 400 to 550 feet above the Missouri. In Dixon County, opposite Vermilion, the loess extends from an altitude of 125 feet above the river to 300 feet, and farther back probably to 350 or 400 feet. It is not unlikely, however, that its base rises even more, so that its greatest thickness is near the river, where it attains, perhaps, 150 feet. At Ponca it is nearly the same, with its base about 75 feet above the river.

The lower surface of the loess rests upon the drift, and the relief of the surface of the latter may be inferred from its altitudes, which were given on a previous page. In most cases, toward the central portions of the region the base of the loess is a nearly horizontal plane, and here we usually find its greatest thickness. Near Florence its base is 75 feet above the Missouri, and it is estimated to be 100 feet in thickness. At Council Bluffs it is probably over 200 feet, but a continuous section of more than 100 feet has not been exposed at any one point. Judging from the external appearance of the bluffs along the Missouri, a similar thickness is attained at several other points from Sioux City southward.

The circumstances of the deposition of the loess and its age will be postponed until we have considered more fully its relations to the moraine and terraces of the principal streams. We now proceed to consider more in detail the features of the loess region adjoining the moraine.

Relation of the loess to the outer moraine.—Beginning near the mouth of the Bazile, the northern boundary of the loess extends nearly parallel with the Missouri, at a distance of 3 or 4 miles from it, to near sec. 8, T. 32 N., R. 3 W. At that point it turns abruptly southward to the southern end of the township and describes a broad semicircle, terminating at its eastern extremity in a high hill, about 6 miles west of St. Helena. From this point to Ponca it follows quite closely along the right bank of the Missouri, receding only near the more important

valley of the Bow. This whole margin has more or less of a dentate character, the projections being high, narrow, and usually extending toward the northwest. The drainage of the loess from this edge west of St. Helena is southward without exception. This would indicate that in its earlier condition, if not at present, its northern edge was the highest portion. From this margin, especially from the vicinity of Santee Agency to St. Helena, the country descends abruptly from 100 to 200 feet down to the Cretaceous clays, which occupy almost the whole surface between this line and the river, the only exception being where drift gravels extend northward from underneath the loess, as has been



FIG. 22.—Section from Boonsboro, Iowa, to the Missouri.

described in connection with the drift. The very striking features of this northern edge of the loess are seen in Pl. XIV.

The altitude of the highest points is about 550 feet above the river. The thickness of the loess there varies from 30 to 100 feet. The eroded surface of the drift below was found at only one point, but so distinctly as to leave no doubt as to the fact. The branches of Bazile and Bow creeks have in many cases worn down into the underlying drift. But over much of the loess region one may travel for miles without finding a pebble. In Dickson and Dakota counties the loess covers the drift very perfectly, no pebbles being found even along streams that are eroded 200 or 300 feet below the general level. The loess in Lyon

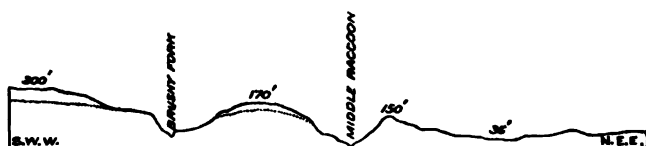


FIG. 23.—Section near south line of Carroll County, Iowa.

County, Iowa, sustains a very similar relation to the Big Sioux to that which it has to the Missouri in northern Nebraska, but its edge is less elevated and somewhat less abrupt. Instead of being 550 feet above the stream it is not more than 250 feet.

Professors White and St. John noted a similar relation in central Iowa¹. Figs. 22, 23, and 24 represent their conclusions.

In the southern part of Lincoln County and the northern part of Union County, South Dakota, the inner edge of the loess is very different from the points already described. Along the lower course of Brule Creek east of Vermilion Gap the loess occupies the hills on the east side, but as the moraine begins to appear on the western side it also

¹ See White's Iowa Report, Vol. I, p. 114; Vol. II, pp. 6, 98, 143.

appears on the west side of the creek and is spread out in shallow beds in an irregular manner upon its outer slope. Where the moraine consists of a few small hills about 9 miles east of Spirit Mound and just west of Brule Creek the inner range, rising 75 feet above the plain west, is very bowldery. The second range, about half a mile east, which rises 30 feet higher, has every appearance of being covered all over its summit with loess. No erratics were found, and badger holes showed only loess with calcareous concretions.

Southwest of Beresford, in the shallow cuts along the railroad, another opportunity was afforded to study this point. In the first cuts nothing



FIG. 24.—Section near junction of Middle Racoon River and Willow Creek, Iowa.

but pebbly clay or disintegrated yellow till was seen below the soil, but about 30 feet below and about a mile distant from that town, which is upon the summit of the moraine, the loess begins to appear. In the first case it was in a portion of the cut covered with several feet of pebbly loam, which may be explained as a wash from the hillside west. A little farther east and 40 feet lower it showed its typical character, and began to cover the hills gradually toward the east. In Lyon County,

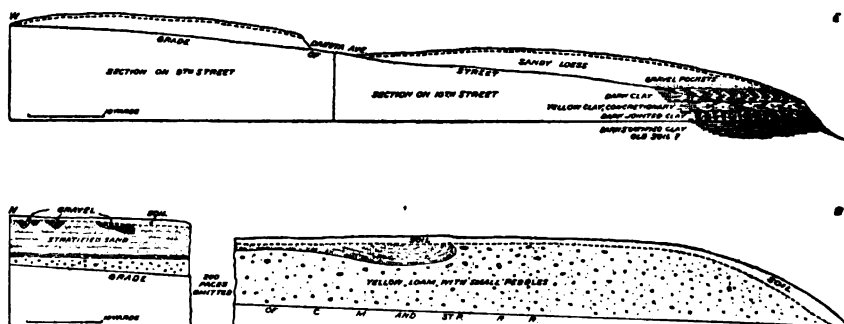
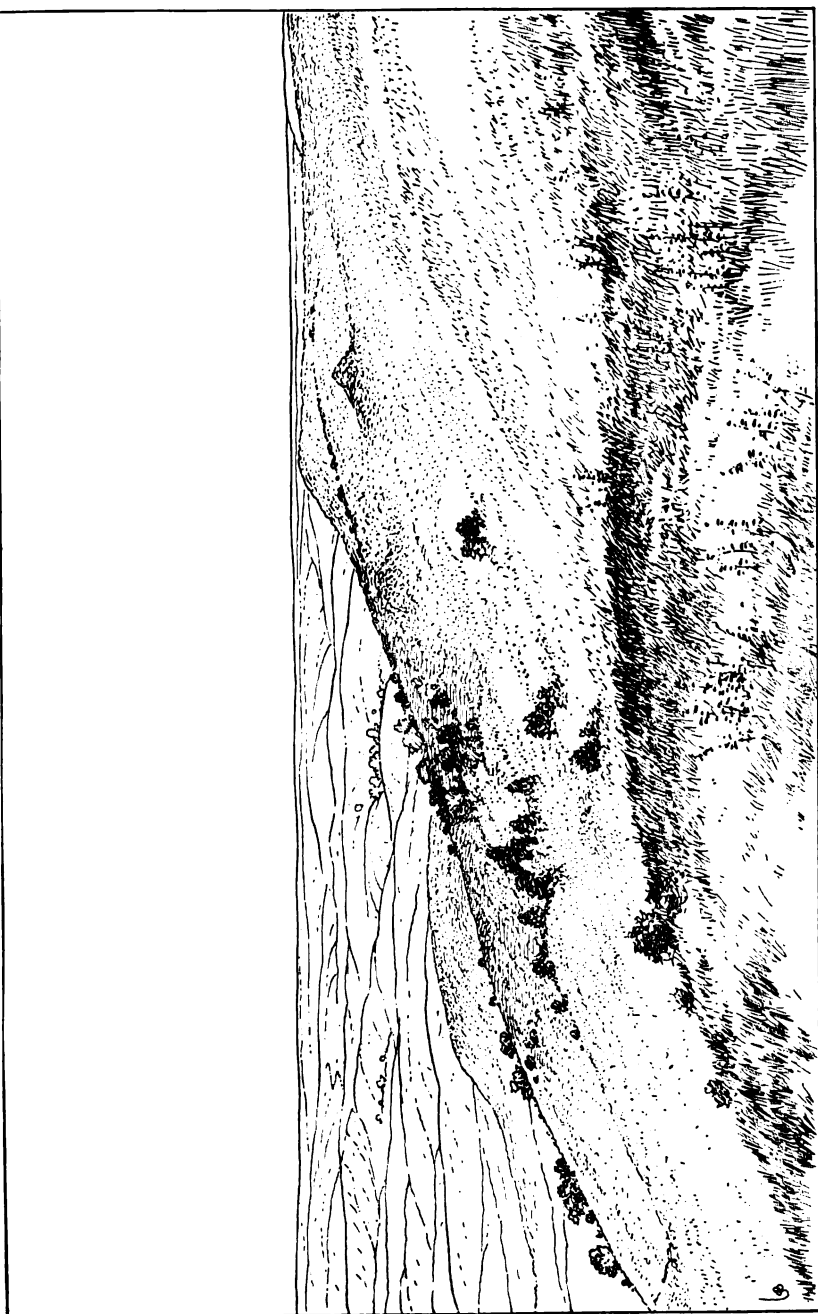


FIG. 25.—Sections at Sioux Falls, South Dakota.

Iowa, and Rock County, Minnesota, the drainage, as in northern Nebraska, is generally southward from the inner edge of the loess.

About Sioux Falls the loess occupies the hills in the bend of the Big Sioux. Underneath it lies darker clay, perhaps an old soil, below which are beds of pebble clay. When the loess was deposited the falls could not have been in existence. Some of the characteristic features may be seen from the sections shown in figs. 25 and 26. It is found rising



EASTWARD VIEW FROM NORTH EDGE OF THE LOESS SOUTH OF HERRICK, NEBRASKA.

about 75 feet above the Milwaukee station, or to an altitude of 1,455 feet above the sea, and is here again close to the exterior of the moraine. This, though arrived at quite independently, corresponds well with its

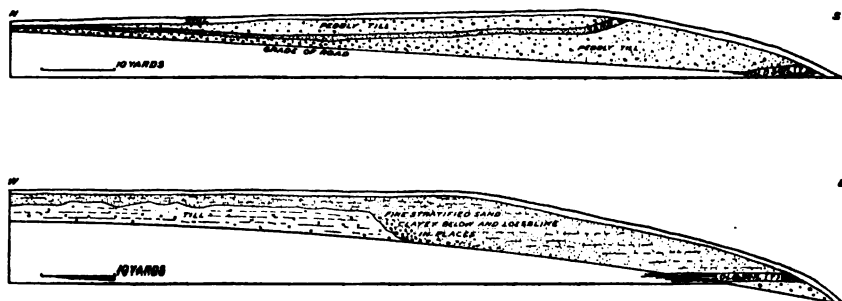


FIG. 26.—Sections at Sioux Falls, South Dakota.

altitude east of Beresford and at Warren, Iowa, and with the reports of Prof. N. H. Winchell respecting southeastern Minnesota.

COTEAU DES PRAIRIES REGION.

This region in some sense may be called the counterpart of the Red Lake region. It lies nearly in the same latitude, occupies an external angle of the moraine, and its features suggest lacustrine origin.

Boundaries of the Coteau region.—The line of separation between this and the moraine on the west may be located as follows: From the vicinity of Brookings southwest to Madison, thence southeast to Hartford and the mouth of Skunk Creek, thence northeast along the north bend of the Big Sioux and east to Luverne, thence north to Pipestone, thence north and northwest to the vicinity of Brookings. The northwest boundary corresponds well with the northeast course of Battle Creek, the southwest boundary, in general, with the west side of Skunk Creek Valley, the eastern boundary with more prominent outcrops of the Sioux quartzite.

Surface of the Coteau region.—The surface may be described in general as a plain lying between the east side of the Dakota loop and the west side of the Minnesota loop of the outer moraine. This plain slopes toward the south at the rate of 4 or 5 feet per mile. Where crossed by the railroad between Pipestone and Madison its altitude is very uniformly 1,690 feet above the sea. Where it is crossed in its southern portion the altitude is from 1,460 feet north of Valley Springs on its eastern side to 1,575 feet on its western side near Hartford. The general elevation there can not be so accurately given because the plain has been very much eroded. As will be seen from the map, its southern portion is much traversed by streams, which have by their numerous branches quite destroyed the surface of the original plain, especially toward the southeast. On the other hand, the northern portion of the

plain, aside from the larger valleys and ancient channels, rarely shows variation of surface of more than 10 or 15 feet. Ponds and shallow basins are found upon this plain in the vicinity of the moraine. More especially is this true west of Skunk Creek and northeast of Madison. On the margin of the plain northwest of Pipestone, as it approaches the moraine, a few broad swells appear. Along the Split Rock are bowldery knolls, which rise above (?) the general surface from 25 to 50 feet. The surface of the plain, where most even, is covered with a thin deposit of silt indistinguishable from loess. This was distinctly observed southeast of Flandreau. It can scarcely be said to be general, however.

Northwest of Flandreau and Egan, lying in the great bend of the Big Sioux, is a plain lower and more even in surface than the one already described. It was traversed from the vicinity of Medary to Egan. Its western boundary has not been definitely determined, but must lie several miles west of that course. When this region was examined the atmosphere was so smoky as to prevent a determination of this point. It is possible that no distinct edge will be found, and that the plain gradually rises to the level of the one farther west—i. e., the general surface of the region. The surface of this lower plain is covered with silt, shows very few bowlders, and only a few quite shallow basins. Shallow sags also lead off into the short ravines running into the Big Sioux. The general surface is very even, and does not show elevations more than about 5 feet in height. Along the valley of the Sioux southward the hills are much lower than farther back, and probably may, many of them, be found to correspond in structure as well as altitude to this lower plain. In a trip southwest from Dell Rapids the highest hills east of Skunk Creek are 1,590 feet in elevation, while west of Skunk Creek the general surface of the country rises abruptly to the higher plain at 1,675 feet above the sea.

Valleys of the Coteau region.—The valleys may be divided into those which are now occupied by streams, which we may call recent valleys, and those which are not so occupied, which may be characterized as ancient channels. They are so related to one another, however, that we shall treat them together. The principal streams of the region are, first, the Big Sioux, then its three principal tributaries, Battle, Skunk, and Split Rock creeks, and two smaller though scarcely less important ones—Flandreau Creek, which lies in an old outlet channel, connected with Lake Benton in the Minnesota moraine, and Deer Creek, leading from another outlet in the same moraine. Both have large valleys, broad, flat bottomed, and with abrupt sides.

Battle Creek rises inside of the moraine, in Badus Lake, and first flows southeast through a broad valley, but after passing through the moraine turns sharply to the northeast. Its valley outside of the moraine is broad and marshy, and, especially its eastern bank, is quite low, about 40 feet below the plain north at the bend. Its lower course

is occupied by open lakes. Leading southeast from near the bend in Battle Creek, and in line with its upper course, is a remarkable ancient channel, crossing the railroad a little west of Coleman. North of Wentworth it is occupied by a shallow lake 3 or 4 miles in length, which we will call Lake Wentworth. Farther east it becomes marshy, and the lower portion of this channel is occupied by a small branch of the Big Sioux. This channel, from its position, seems likely to have been once occupied by the stream which flowed through the gap in the moraine to the northwest and which later, turning northeast, began the valley of Battle Creek. Herman, Madison, Brant, and Skunk Creek lakes occupy a very remarkable valley. The first of these lakes lies surrounded by the moraine. There are numerous channels from the slopes of the moraine leading into it, some from the south, but the more important, which are now occupied by copious streams, from the west and north. The lake is a beautiful sheet of water, of somewhat crescent shape, and surrounded with quite abrupt hills. The peninsula from its eastern end is covered with trees. Leading east from this lake is a system of channels, of which there are two principal ones. One leads east and southeast from the north portion of Lake Herman to Lake Madison, thence southeast along the course of that lake and Brant Lake, gradually running out beyond. In this valley flows the stream which connects Lakes Herman and Madison. The other valley, beginning with the southern point, is not so deep and continuous at first, but is occupied by several smaller lakes and ponds, which lead to a distinct channel within a couple of miles. It extends approximately parallel with the first channel, with which it connects now and then by crosschannels. The series of marshes along the southwest side of Lake Madison lies in this channel, and south of Brant Lake it becomes the principal channel of the two and conveys the waters which flow from Lake Madison and Brant Lake, and which form Skunk Creek. The resemblance of Lake Madison to a mighty river is very striking. Its winding course and its alternation of abrupt banks and low bottoms with trees deepen the impression. In 1881 it first, to the knowledge of white men, began to flow out by a cross channel into Skunk Creek. The hills between these twin channels rise in some cases to more than 100 feet, and have their full share of bowlders.

It is interesting to compare this channel with the Lake Wentworth channel. Both of them have a southeast direction, both are excavated in the higher plain of the region, and both seem to have had their lower courses changed at a subsequent stage. While the stream occupying the Lake Wentworth channel turned northeast, the one occupying Madison Lake channel turns southward. On the other hand, they differ in that the lake portion of Madison Lake channel was still occupied while that of Battle Creek channel was vacated. Hence we find that the Lake Wentworth channel is excavated only to the depth of 40 feet below the plain, while that of Lake Madison is 100 feet below the

plain. It should be noticed also that the Madison Lake channel is mainly external to the moraine, while the other passes through the moraine. We may notice also a correspondence between these two streams and the two principal branches of Smith Creek, in the Red Lake region.

The lower course of Skunk Creek lies in a broad, flat-bottomed valley with abrupt sides, and with its western bank, where it has been examined, nearly 100 feet higher than its eastern. Furthermore, the western edge of its valley is covered with bowldery knolls, suggesting a morainic origin; but more probably they are of the same formation as the bowldery osar-like ridges to be described in a future section.

Split Rock rises in Pipestone County, Minnesota, and flows south and southwest to the Big Sioux below the great bend. The most important tributary, which is in some sense the principal stream, is Pipestone Creek, which, rising near the same point, joins the Split Rock on the Minnesota line 6 miles south of the northeast corner of Minnehaha County. Its valley has been so affected by the red quartzite that it has been frequently wrongly mapped. In Palisade Township it passes through a narrow gorge about 4 miles in length. This is walled below on either side with perpendicular walls of quartzite. These rise about 60 feet above the water, and the gorge in its narrowest place is about the same in breadth. The confining of the stream by this rock has prevented the widening of its valley, as is frequent in other streams of the region. It is not probable that this gorge is mainly the work of the Split Rock, because its rocky sides are not continuous. They recede at many points some distance from the stream, and become buried by the drift. In such localities they are, nevertheless, cut into chimneys and cliffs, as though they were formed by some agency long before the later deposit, possibly by ages of weathering, perhaps by the action of the sea itself. Just below Palisade another tributary comes in from the north which has a wider valley, and on this account has had the credit of being the main stream. The exposure at Palisade has been well described by Mr. Warren Upham in the thirteenth annual report of the Minnesota survey. Considerable valuable information has also been given concerning this locality in the Fifth Annual Report of the United States Geological Survey, page 201. The plate facing that page, however, gives an exaggerated idea of the breadth of the gorge. As the treatment of the older rocks is foreign to this paper, the reader is respectfully referred to those works for further information.

About the center of Brandon Township is an exposure of diorite for some rods along the west bank of the Split Rock.¹ It is much decomposed and is presumably an intrusive formation. In sec. 23 the red quartzite is again exposed near the surface of the stream, with several feet of chalkstone (Niobrara) directly above it. The junction between

¹ This is the rock which, since my examination of it, has been reported by Prof. W. H. Hobbs to be olivine-diorite.

the two, however, is not exposed. The numerous striae found upon the rocks in the localities mentioned, and others farther east, will be considered in detail in another section.

The Big Sioux enters the region under consideration near Brookings, in a valley from three-fourths to $1\frac{1}{2}$ miles in width. Above the mouth of Battle Creek its valley is quite wide and about 140 feet below the high plain west, which is a narrow extension of that occupying most of the region. From that point to Egan it is bounded by the lower plain, which at the latter point is about 100 feet above the stream. This plain seems not to slope so rapidly as the stream, for at its upper end, near Madary, it is not more than 80 feet above the stream. The valley of the Big Sioux as a whole fails to present the abrupt sides and sharp edges which commonly characterize the other valleys of the region. A reason for this feature may be found in the check to its erosion by its crossing two important ledges of quartzite. One of these is at Dell Rapids. At Sioux Falls the course of the stream has been such that it has failed to excavate so deeply; probably the rock has not been so much exposed to erosion, for its surface is more than 100 feet lower than at Dell Rapids, and the force of the stream has been expended over a much wider surface.

The Dells at Dell Rapids.—There are three gorges at Dell Rapids; one is known as the Wet Dell, one as the Dry Dell, and the third is the present course of the Big Sioux. The course of the stream at the rapids is nearly due west. The Wet Dell leaves the present channel south of the town and takes a south-southwest direction for about $2\frac{1}{2}$ miles, where it strikes the present channel again. It is filled with water through most of its course and might easily be taken for a stream that has been dammed. When the Big Sioux is flooded the water flows through this channel. The Dry Dell leaves the present channel near where it turns south and continues its course westward. It is of less width than the Wet Dell, but is filled with earth to within 12 feet of the top of the rock. Its western end is hidden under the hills forming the west side of the valley. The present channel has excavated the rock to less depth than the Wet Dell. There are two or three pillar-like rocks standing in the center of the stream to a height equal to the ledge at the side. One of these has been utilized as a pier for the railroad bridge. Below the Dells the hills along the Big Sioux Valley are rarely over 80 feet above the stream. The surface of the quartzite above Dell Rapids is compact and even-topped, but shows few striae. East of the Wet Dell a few were found bearing S. 25° E. to S. 40° E. The red quartzite appears again about 4 miles west of Dell Rapids, where it is 100 feet higher than at Dell Rapids.

Below Dell Rapids the Big Sioux continues the general features of the valley above and keeps a straight southerly course to the southern point of the Great Bend at Sioux Falls, where it turns sharply, first northeast, and then northwest and north, falling over the ledge of

quartzite (a height of about 80 feet), and then continuing in a northeasterly course to the vicinity of Brandon, where it turns sharply to the south again, which course it keeps for some distance. The distance from its sharp south bend to its sharp north bend is 10 miles, directly northeast. The fall of the river through this region may be learned from the following elevations, derived from railroad levels. In each case the level of the water is given.

Elevations along the Big Sioux, showing grade of river.

	Feet.
East of Volga.....	1, 596
Near Egan.....	1, 510
At Dell Rapids.....	1, 476
West of Sioux Falls.....	1, 403
At the Chicago, St. Paul, Minneapolis and Omaha Railway east of Sioux Falls.	1, 381
At the Chicago, Milwaukee and St. Paul Railway.....	1, 369
West of Brandon.....	1, 281
East of Canton.....	1, 217
Riverside near mouth.....	1, 079

Great Bend of the Big Sioux.—The bend of the Big Sioux at Sioux Falls is remarkable in two or three particulars. In its present course it flows south to the north edge of the quartzite ledge, it would seem for the express purpose of forming a durable series of rapids for water power. The Sioux quartzite is exposed west of the city near the level of the stream, and east of the town over nearly the whole surface of the falls, which are more than half a mile in length. The neck separating the bottom land north of the town from the gorge northeast is considerably lower than the hills in the bend farther south, and is less than 20 feet above the bottom land on the northwest. Its form and structure indicate that at one time the stream flowed across the neck. Why then did it not continue to do so and cut down through the till which probably forms the most of it? If it had done so it is probable that there would have been no falls; at least not until the river had cut back to the rock at Dell Rapids. (It may be that the quartzite occurs south of that place, but such is not known to be the fact.) The answer is believed to be probably the following: We have seen that there was much drainage from the ice sheet northward south of Sioux Falls, and when the ice occupied the outer moraine Skunk Creek was the channel by which all the Glacial streams from the vicinity of Volga to Sioux Falls found escape. Even supposing that the Big Sioux at that time took the shorter course, it is easy to see that the western side of the channel would be cut down most rapidly, and in this way the main channel would be drawn westward and southward until forced northward by the contact with the moraine and strong currents pouring over the lower portion of the moraine at that point. It may be stated here that while we have given, as we suppose, the immediate cause of the bend, the primary cause is to be found in the advance of the ice across the pre-Glacial course of the Big Sioux. No developments have been made

to corroborate the supposition, but it seems not improbable that the pre-Glacial course of the Big Sioux may have been southward into the Vermilion, and that in the advance of the ice toward the east there may have been a damming of the streams coming from the north, and the formation of a glacial lake over this region somewhat as was conceived to have been formed in the Red Lake region; with this difference, however, that while in the latter case it was of temporary duration, in this case the lacustrine epoch continued until the basin had become completely filled with drift material.

Bowldery knolls in the Coteau region.—In speaking of the moraine, reference has already been made to systems of osar-like ridges found on its outer slope. These extend out upon the extramorainic plain, and we will here give the more detailed description which has been promised. The system in this region which has been most closely observed is the one 5 to 6 miles northeast of Montrose. Its more prominent features are illustrated in Pls. IX and X.

The bowldery knolls are from 15 to 35 feet in height, and are arranged for the most part in a rude linear system lying in the bottom of a shallow valley which leads from a col or sag in the moraine eastward and southeastward to a branch of Skunk Creek. The head of the system, which begins quite gradually, lies along the north side of a channel-like lake half a mile long and perhaps a quarter as broad. This lake cuts the crest of the moraine transversely. As in the case of similar knolls near Crow Lake, the surrounding slopes are comparatively free from bowlders. Like that system, also, this one receives a branch which lies in a valley joining it from the northwest. The recency of the topography is attested by the occurrence of basins beside the knolls, which are yet undrained. The lake is about 40 feet below the highest adjacent point on the crest of the moraine, about 240 feet above the East Vermilion at Montrose, and 170 feet above the plain farther west. This system, like the systems in the Red Lake region already referred to, lies above the level of the loess.

The interior of the knolls was nowhere exposed, hence we can say nothing of their structure from direct examination; but from their general appearance as compared with some which were excavated northwest of Waterbury, South Dakota, we should expect to find them largely composed of stratified material.

Along the western edge of Skunk Creek Valley, also, there are bowldery knolls which rise to the height of 20 or 25 feet above the ponds just west of them. Though these have not been connected with gaps in the moraine, their proximity to an important stream and their separation from the morainic hills farther west by a plain 3 or 4 miles in width, as well as their lower elevation, may be taken as evidence that they belong to the same class of deposits as those already mentioned.

Along the Split Rock are found systems of knolls which appear to

be of a rather novel character. They are of rounded form and are found in clusters rather than in ranges. The most important cluster that has been observed is about 6 miles southwest of Pipestone. They rise to the height of from 25 to 40 feet above the general level and nearly 200 feet above the Split Rock southeast. They are arranged around the head of a valley leading into that stream. The slope of the southeast side of the valley, rising 120 feet, is wholly occupied with the red quartzite. There are about fifteen knolls in this cluster, and it occupies most of the surface of two sections. A few others are found along the east side of the Split Rock below the junction with Pipestone Creek, but they are found only in clusters of two or three. From their form and altitude they stand out conspicuously, although they do not attain the height of the first cluster, not rising generally more than 150 feet above the stream. These, which are near Garretson, South Dakota, have been referred to on a previous page. All of these knolls present the same features. Their summits are covered with pebbles and a few small boulders. Two exposures were examined which had been made by the opening of the summits of these hills for gravel and sand. Their interior structure, where examined, was found to consist of irregular layers of pebbly clay and stratified gravel and sand to a depth of 5 or 6 feet. Below that for 5 or 6 feet farther pure sand was found. Whether the sand comprises the bulk of the hill has not been learned. Their form and position suggest the idea that these hills were primarily dunes which have been thinly veneered with drift and somewhat shaped by aqueous and glacio-natant action. This is not easily reconcilable with the supposition that this locality has been swept very lately, if at all, by an ice sheet.

Hummocks in the Coteau region.—At various points the red quartzite ledges present the peculiar phenomena which may most aptly be described by this term. The upper layer of the rock becomes bulged, and is heaved up in a domed or conical form to the height of 5 or 6 feet. These have been described by Prof. N. H. Winchell in his report on Rock County, Minnesota. The surface of the hummock is covered by these blocks in their natural order, but with the joints between them broadening more and more toward the center of the hummock. That they are of recent origin is indicated by the occurrence of striæ around them, as if they were not in existence when the striation was in progress. Professor Winchell's suggestion that they may have been caused by ice—i. e., alternate freezing and thawing with the change of seasons, aided by the force of vegetation and a little soil gradually getting into the openings—seems quite plausible. They are apt to occur at equidistant intervals.

Striæ in the Coteau region.—The red quartzite, which is frequently exposed in this region, abounds in striæ. They present several novel features. The striæ are distinctly shown, rarely more than 2 feet in length and not often more than one-eighth inch in depth. They are

commonly quite minute. They are frequently attended with crescentic cracks, whose ends incline toward the direction of movement. These are arranged parallel with one another at approximately equal distances. Systems of these are found with breadths of from one-half inch to 18 inches, and may sometimes be 3 feet in length. The larger ones reveal more of a parabolic than circular form. In the larger systems the longer cracks are intercalated with the shorter ones, suggesting the coexistence of two systems of vibration. The general appearance of such a system is fairly represented in fig. 27 (1), which was carefully drawn from nature. Not infrequently the striæ with which these crescents are connected have been worn away, and the crescentic cracks are the only record remaining of the original marking. The depth to which the cracks extend varies from the merest trifle to at least an inch, and it is not improbable that further examination may increase this figure.

The inclination of these cracks to the surface, near the axis of the system, is forward, but gradually turns backward as the distance from the axis increases, until it may incline quite strongly backward.

Besides these cracks, which are clearly referable to ice action, there are others resembling them somewhat, in which the crescentic marking turns in the opposite direction. These are also apt to show an equidistant arrangement, but are never as near together nor as regular in their shape and position as those already described. They may be ascribed, with considerable confidence, to the ripple marks preserved in the stratification of the rocks. Fig. 27 (2) shows a case where both these kinds of markings occur.

A careful study of the striæ of this region shows more variation in direction than has been commonly ascribed to glacial action. This will appear from the table of striæ given below. Not infrequently three or

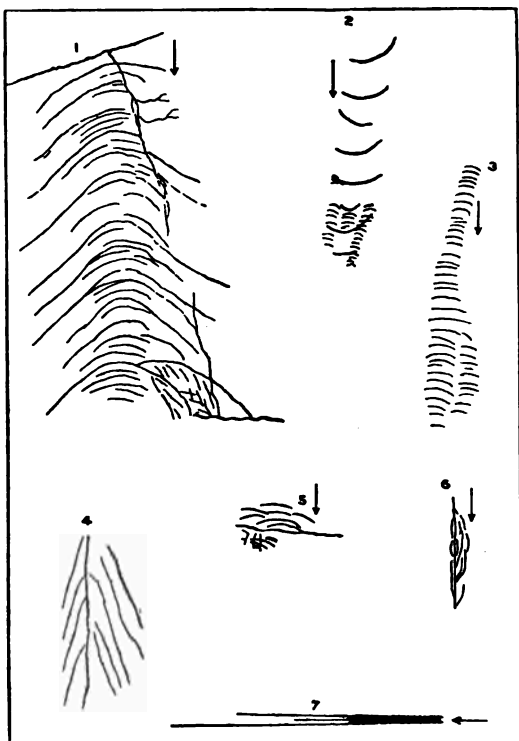


FIG. 27.—Various markings on Sioux quartzite.

four systems of striae, of widely varying direction, occur upon the smooth surface of the rock with equal distinctness. Some of the novelties which have been observed are shown in fig. 27. Curved striae not infrequently appear.

Striae found in the Coteau des Prairies region.

[Corrections are made for magnetic variation.]

Locality.	Direction.
Pipestone, Minnesota:	
Near the Three Maidens.....	{ S. 30°-26°-28°-40° W. S. 14° E.
Near Pipestone Falls.....	{ S. 1°-19°-24°-27°-28°-37° W. S. 0°-2°-3° E.
Pipestone City.....	{ S. 22°-23°-25°-26°-32°-37°-38° W. S. 34°-42°-38°-45° E.
Three miles southwest of Pipestone...	S. 3°-7°-13° E.
About 8 miles SSW. of Pipestone.....	S. 22° W.
Four miles north of Palisade.....	S. 14°-18° E.
Palisade:	
At the southeast edge of exposure.	S. 33°-38° E.
One mile east.....	S. 23° E.
One and one-half miles south of Palisade.	S. 13°-18°-28°-48°-53°-58°-63° E.
Two miles north of Valley Springs....	S. 8°-53°-62°-63° E.
Northwest corner of Iowa.....	S. 8°-9°-13°-16°-18°-19°-23°-30°-38°-53° E.
Opposite mouth of Split Rock:	
Inside of the moraine.....	S. 13° E.
One mile outside of the moraine..	S. 13° E.
Sioux Falls:	
Near Milwaukee station.....	S. 13° curving to 8° E.
East of Cascade mills (recent)....	N. 28°-45° W.
Southeast of Queen Bee mill.....	S. 43°-53° E.
East of C., St. P., M. & O. station.	E. [mag.] = S. 88° E.
Dell Rapids, east of Wet Dell.....	S. 13°-23°-28° E.
Four miles west of Dell Rapids.....	{ S. 2° W. S. 3°-13°-18° E.

CHAPTER IV.

THE DRIFT REGION INSIDE OF THE OUTER MORAINE.

This is naturally divided into three principal parts: The second moraine, the region between the moraines, the portion inside of the second moraine.

SECOND OR GARY MORAINE.

Several circumstances combine to make the second moraine less prominent in height, in breadth, and in complexity:

(1) It was formed upon a nearly level plain left by the great ice sheet. There were therefore no very prominent features to distort or elevate the moraine, as was the case with the outer moraine.

(2) Another circumstance, which was also a result of its formation upon a plain, was its predominating tangential drainage. As the ice sheet retreated from the principal moraine, its edge in general withdrew to lower ground. Hence while occupying the second moraine the waters tended to flow along its edge to the two principal streams, the James and the Vermilion. This tangential drainage tended to erode the moraine in some cases and to bury it in others.

(3) The ice sheet had probably diminished considerably in thickness, at least toward its lower margin; therefore its pushing power and probably its velocity had decreased. Both of these would diminish the amount of the material crowded into the moraine.

(4) It is not unlikely that the period of formation of the second moraine was much shorter than that of the first.

Northeast of Turtle Point 6 or 8 miles, and occupying the narrow space between Firesteel and Sand creeks, is a range of stony hills presenting the usual features of a moraine. It rises frequently to the height of 100 feet above the general level, or 130 feet above Sand Creek. Gravel and sand are very abundant, also boulders of limestone and gray granite. Its extent northwestward has not been determined, but it probably is to be connected with stony knobs southwest of Wessington Station. From the before-mentioned locality northeast of Wessington Springs, the moraine extends in a discontinuous system of irregularly crescentic clusters of sharp knobby hills which are from 20 to 60 feet above the very even plain. Their convexity is toward the west. The inner edge, along which the principal range lies, passes $3\frac{1}{2}$ miles west of Woonsocket, where it rises to an elevation of 75 feet. It is there called the Pony Hills. which are sketched in fig. 28. The

ridge continues 4 or 5 miles farther, then disappears. At Twin Lakes another ridge rises to the height of 30 feet and continues south 2 or 3 miles. Light bowldery ridges just east of the Firesteel in Jerauld County should doubtless be reckoned as portions of the second moraine.

South of Twin Lakes the principal development, which, however, is little more than a broad swell surmounted with a few bowldery knolls, passes 5 or 6 miles west of Letcher in a south-southeasterly direction to the Firesteel northeast of Mount Vernon. South of the Firesteel, in the northern portion of T. 103, R. 61, the surface rises into broken gravelly ridges extending in a southeastern direction. Between them are numerous basins elongated in a northwest-southeast direction, which, from their position and connection, suggest the action of a stream successively shifting from one to another toward the northeast. Possibly the Firesteel formed them after it entered the moraine and followed

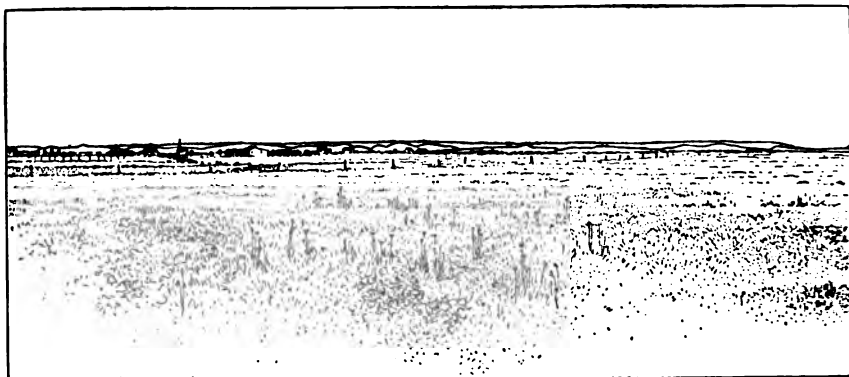


FIG. 28.—Pony Hills, near Woonsocket, South Dakota.

the retreating ice. Three or 4 miles west of Mitchell one of the more prominent valleys near the outside of the moraine connects with Enemy Creek. Four or 5 miles south of Mitchell are two ranges of long narrow hills, about 60 feet in height, lying west-northwest, east-southeast; these are known as Enemy Creek Hills (fig. 29). A view from them shows less conspicuous knolls in the plain to the southwest. These hills form one of the most prominent portions of the moraine. A peculiarity of their position is that they lie on ground lower than that a little northeast of them. One mile east of the junction of the Firesteel and the James is a very conspicuous hill, locally known as Medicine Hill. It rises about 210 feet above the James River, and 90 feet above the general level of the lacustrine plain surrounding it east, north, and west. A range of low hills extends south from it and curves to the southeast. It is evidently the head of an interlobular moraine, which became nearly a glacial island during the latest occupation of this moraine.

West and southeast of Rockport the banks of the James show several stony knobs. These are especially numerous in the northern portion of T. 101, R. 58. It would seem that here, near sec. 2, was the apex of a reentrant angle of the moraine. Extending from near sec. 33, 2 miles east of Rockport, in an east-southeast direction, is a long, shallow, ancient channel, now occupied by a miry slough 2 or 3 miles in length. This is at a level of about 110 feet above the James. About one-half mile east of the river bluffs at Rockport it makes a slight bend from a south-southwest direction, which is about in line with the upper portion of Pierre Creek, to a southeast direction. This part of its course is among very gravelly knobs, rising about 40 feet above it. Among them along its west side is a line of small kettle-hole ponds nearly parallel with it. It continues south to the ravine of a small

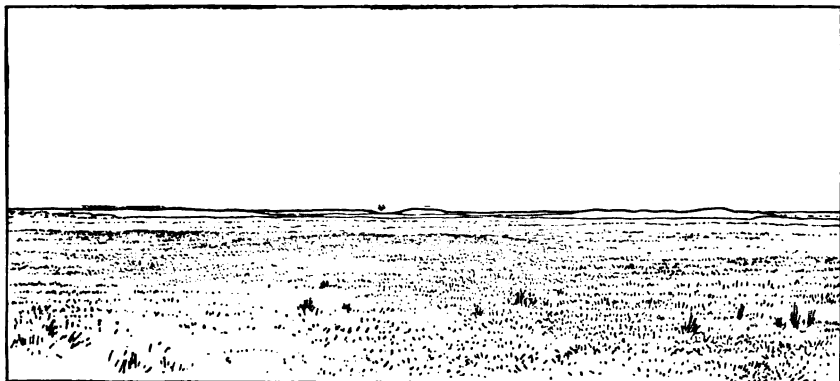


FIG. 29.—Enemy Creek Hills from the northeast. v Enemy Creek.

creek which connects with the James. This channel seems to be a trace of the internal drainage of this angle of the moraine.

In or near sec. 33, T. 101, R. 58, is a cluster of morainic knobs which give an extensive view of the plain to the east, although not apparently up to the level of the land west of the James. Southeast from this point the inner edge of the moraine extends quite directly to Wolf Creek, 2 or 3 miles above its junction with the James. Along considerable of this portion there is found just within the moraine a chain of shallow sloughs and ponds, the moraine itself appearing somewhat like the edge of a terrace rising 40 or 50 feet above these ponds.

In or near sec. 4, T. 99, R. 58, is a cluster of high stony knobs interspersed with deep ponds, some of them covering several acres. These seem to connect in a semicircular curve of low and scattered domes with the high knolls near sec. 33, before mentioned. The moraine has not been definitely traced farther east of James River.

The line described thus far is clearly the inner limit of the moraine, comprising some of the last-formed ridges. It should be remembered that the retreat of the ice sheet had from the nature of the case been

more rapid on the west, hence the ridges are more scattered. Other knolly areas which should be correlated as earlier-formed members of this moraine may be mentioned as follows:

Several miles of knolls along the east side of the Firesteel, about 10 miles west of Woonsocket; another, similarly related to the same stream, 12 miles west of Letcher; a broad strip 2 or 3 miles east of Mount Vernon, extending southeast to Enemy Creek a few miles west of the before-mentioned Enemy Creek Hills; light ridges 2 to 3 miles north of Olivet, trending east of south. Possibly the stony hills east of Olivet and those northeast of Scotland are a modified portion of this moraine, but more likely they are of an older nature. Then, on the north and east of James Ridge the moraine appears again, first feebly, but rising quite markedly as it turns east across the James in the southern border of T. 95, R. 55 and 56, being specially prominent a few miles south of Walshtown. Thence northeast for a few miles it failed to form, probably because at that time the main drainage was in that direction rather than in the line of James River. In the southeastern part of T. 96, R. 55, it gradually rises again.

About 8 miles southeast of Menno is the rather abrupt southern end of a morainic ridge, which extends northward and circles round the northwestern extremity of Turkey Ridge, from which it is separated by a broad, shallow valley. In this valley are the head waters of Clay and Turkey Ridge creeks. Having passed about halfway between Freeman and Childstown the moraine takes a turn more to the east and crosses the West Vermilion halfway between Marion Junction and Parker. Through this portion of its course it may be described as a broad, even-topped swell, rising about 50 feet near Menno, 140 feet near Freeman, and 75 feet near Marion Junction, above the plain to the northwest. Its inner surface slopes rather abruptly. Its outer slope declines very gently. This latter character is best developed southwest of Parker.

One of the most conspicuous points of this moraine is found in sec. 2, T. 99, R. 54, close to the valley of the West Vermilion. It rises about 160 feet above the stream and about 75 feet above the general level. From this point the moraine keeps a course about midway between the East and West Vermilion east of Canistota and northward. While both inner and outer slopes are encroached upon and modified by the drainage into the Vermilions, the summit shows numerous ponds, and, at intervals, low stony knobs. The gap through which the West Vermilion passes is quite narrow, with abrupt sides. Five miles west of Montrose the moraine is a simple continuous low swell, a little roughened on its summit. Shallow basins are more numerous on its outer slope and summit. Along its outer foot they form a connected chain in a shallow sag running parallel with the moraine. The summit rises 45 feet above the plain outside and 30 feet above that within.

Similar features characterize it also east and northeast of Howard,

except that rather conspicuous knobs appear here and there, and it approaches more closely to the East Vermilion, its crest being a little west of Winfred. A remarkable line of broad ponds, just east of the summit of the moraine, extends for 10 or 15 miles parallel with the East Vermilion and 2 or 3 miles west of it. This corresponds to the smaller one before noted west of Montrose.

REGION BETWEEN THE SECOND AND PRINCIPAL MORAINES.

GENERAL CHARACTERISTICS.

This region differs from that outside the moraine in several well-marked particulars:

(1). First and most prominently, in the absence of erosive topography, the streams traversing it being usually limited to narrow channels with abrupt sides. There is little or no trace of watersheds. One does not dream of the nearness of a stream till he comes upon the immediate edge of its channel.

(2). The surface everywhere manifests what may be called a sink-and-swell topography. Sometimes the swells or low ridges are much elongated, and have a general trend somewhat like the waves upon the sea. At other times the elongated character is not prominent where there is an indiscriminate mixing of low, rounded domes with shallow, circular basins.

The amplitude of undulation, or the ratio of the difference in altitude between the tops of the hills and the bottoms of the depressions to the distance between hilltops, varies greatly in different portions. In many cases it may be 5 feet to a mile or a mile and a half. Perhaps nowhere in the whole area under consideration is it more than 40 feet to a half mile, and examples of this extreme occur but rarely.

(3). Nothing like buttes is found in this region. While this is true in general, there are inequalities of great extent, probably due to pre-Glacial topography, which will be mentioned as we describe the area more in detail.

WESTERN REGION.

Under this head we would include all of the country lying west of a line running north from the Choteau Creek Hills to the moraine and outside of the latter. This has an oblique, fan-like form, with its narrow or handle portion extending northward, east of Turtle Ridge, and drained by the north branch of the Firesteel.

Where this widens, south of Turtle Ridge, there begins a valley extending southward which is now occupied by the upper portion of the West Firesteel, then with White Lake and the valley of Pratt Creek. This valley lies approximately parallel with the moraine west of it. Although through the most of its course it now contains but little water, it bears evidence of having been at some time occupied by

a stream approaching the James River in size. The watershed between White Lake and the West Firesteel is very low. One would suspect on first sight that the drainage from White Lake was into the Firesteel. Pratt Creek in its lower portion, near Oastalia, has eroded a valley over 200 feet in depth, along which are immense beds of gravel and numerous boulders.

South of the Firesteel the general level gradually rises to an altitude of over 1,500 feet at Plankinton and beyond 9 or 10 miles, where the country begins as gradually to slope southward, forming a broad, low swell running east and west, which displays an amplitude of undulation of 5 feet to the half mile. Upon its southern slope lie the deep valleys of Andes and Wet Choteau creeks. About their upper courses, in the vicinity of Grandview, the surface of the country is unusually rough, the amplitude being from 35 to 40 feet to the half mile. The general level of the country gradually rises again as it approaches the moraine southwest, but it does not extend to the moraine, for from the vicinity of Pratt Creek to the Choteau Creek Hills there is a broad shallow valley extending parallel with the moraine, which seems to have been formed by the flow of water toward the principal outlets. This valley near the southwest end of Andes Lake is over 300 feet below the general level of the country south. It is occupied by the tributaries of Pease Creek, by the upper portion of the creek flowing through the Andes Lake Outlet, and by the middle course of Choteau Creek. Elsewhere, also, there are dry channels extending through it, which are probably filled with water in springtime.

Aside from the variations in level which have already been alluded to, there is a more general slope of the whole area toward the east. Yorktown is 230 feet above Mount Vernon, according to railroad levels, which indicates a slope of 10 feet to the mile; yet no one in traversing it would speak of it as other than a very level plain. An indication of a similar slope is derived from a preliminary survey between Chamberlain and Springfield. About 9 miles northwest of Lake Andes the altitude is 1,665 feet, also by railroad levels, while in Lower Choteau Creek Valley, likewise inside the moraine, it is 300 feet lower.

More evidence of this eastward slope and of its probable recent origin is seen near White Lake, and also near Lake Andes, in the apparent change of drainage in recent times. As before mentioned, White Lake and the upper portion of the West Firesteel lie in the same valley. The country east is level and much lower than the country about Plankinton. Evidently the drainage of the region was at one time southward into Pratt Creek. Such must have been the case until the ice sheet had receded nearly to the second moraine. At that time, or possibly considerably later, the drainage from the southwest Westsingtons and Turtle Ridge turned eastward, beginning the West Firesteel. This may, it is true, indicate nothing more than the withdrawal of the ice, without change of slope.

At Lake Andes the evidence seems more strongly in favor of the recent tipping of the region. Extending southwest from the southern end of Lake Andes through the gap is a water course less than 10 feet above the water in the lake, which appears as though it had been recently occupied. Southeast from the central portion of the lake extends a long narrow slough, connecting, it is believed, with Wet Choteau Creek. That this is the fact is not certainly determined. Its occupancy by water for several miles in that direction has been observed. The natural suggestion which comes to mind in considering this case is that the plain about Lake Andes has been tipped toward the east, so that its western outlet is now dry, and its waters are seeking drainage toward the southeast by what was, perhaps, formerly a tributary of the lake.

Other reasons for believing in a recent westward elevation of the country will be considered further on. This case is more significant than the last because we can hardly explain the westward flow by the occupation of the eastern outlet by the ice, as in the previous case. We see no reason for supposing that the ice would linger longer in the lower Choteau Valley than near the Andes Lake Outlet, but contrariwise.

Ancient lakes.—In this western region certain areas bear evidence upon the surface of lacustrine origin. These are found, as before stated, in the valley of the West Firesteel, which may be considered as a former extension of White Lake. Another is found southwest of Mitchell, extending from the second moraine southward to the vicinity of Plainview. In both these regions the surface is very level, there being little or no trace of the undulating surface usually found upon the till. Crossing T. 100, R. 62, on the borders of this lacustrine area are two or three light and disconnected lines of low stony ridges suggestive of morainic action, but possibly due to thrusts of ice against the shore. Along the western border of this latter lacustrine area rise Pony Creek and Twelve-mile Creek, which flow eastward to the James, in valleys resembling those already described.

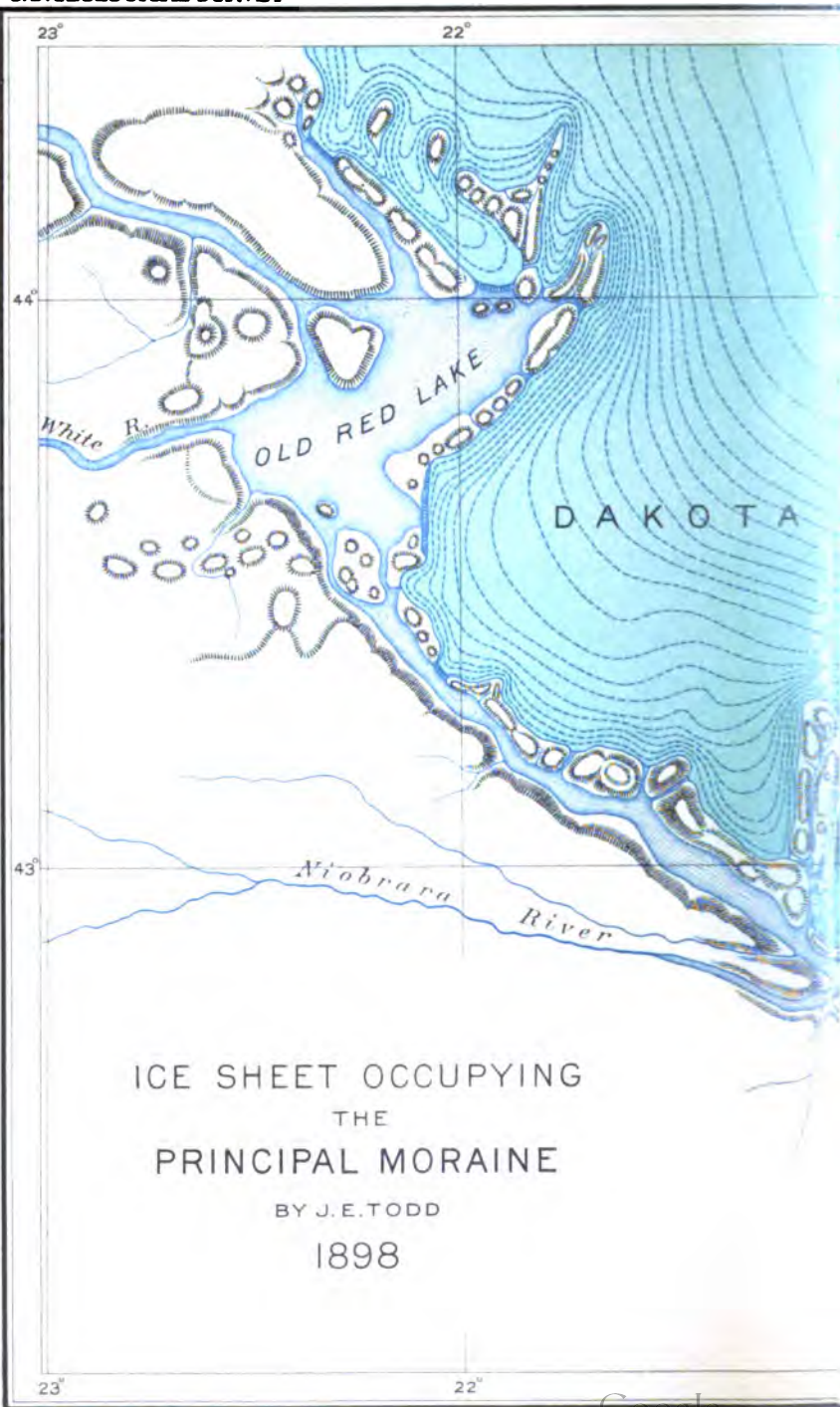
Ancient channels.—Besides the ancient valley of Pratt Creek and that lying inside the moraine from the Cedar Creek Hills to Choteau Creek, which have been mentioned in our general description of the country, there are several minor ones which are not so closely connected with the general topography.

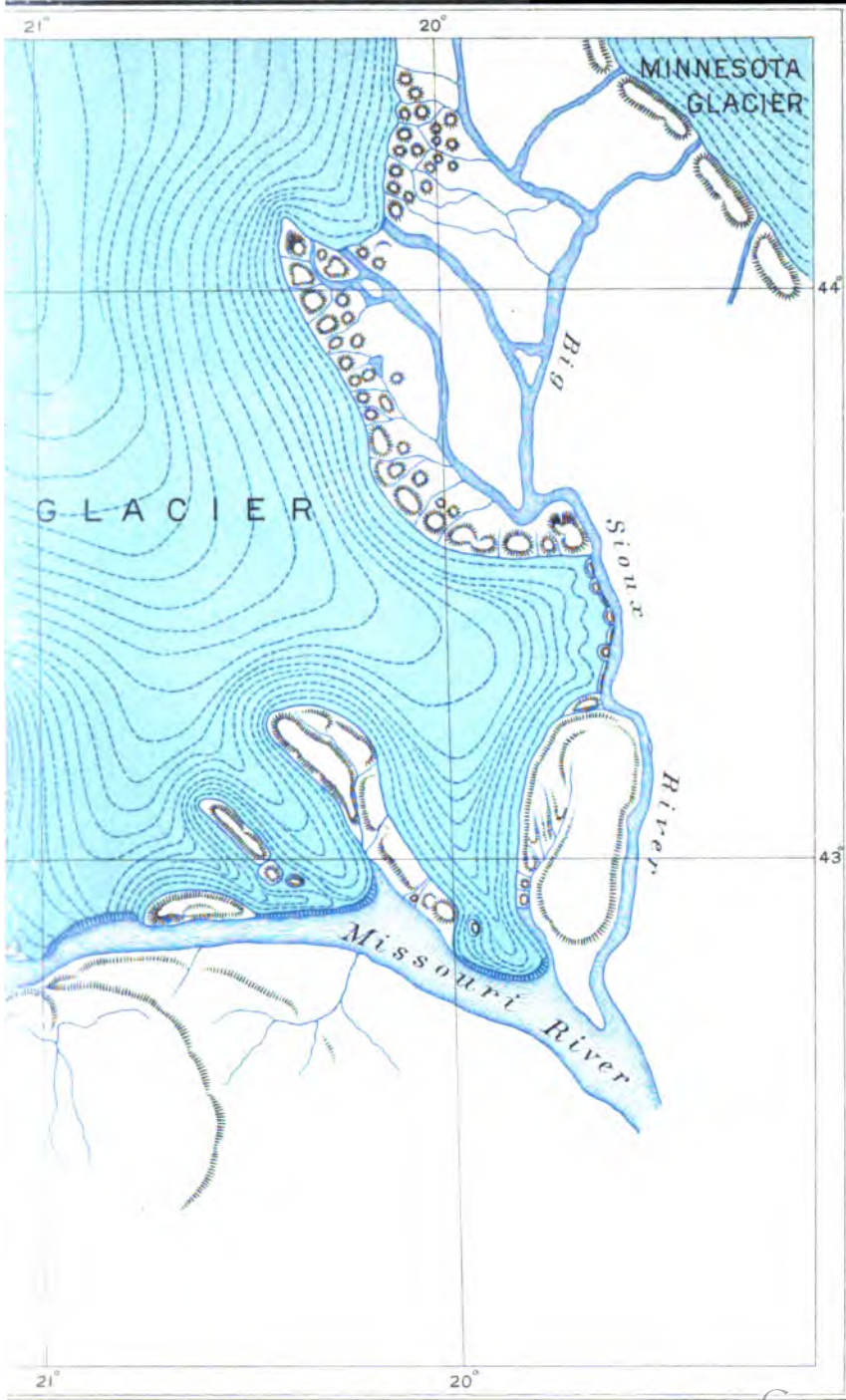
A channel extends in T. 104, R. 63, from the Firesteel to the origin of Enemy Creek. In sec. 34, T. 102, R. 61, a narrow channel with abrupt sides and 40 feet in depth leaves the north branch of Enemy Creek and extends southeast to a branch of Pony Creek. The verification of this last statement was kindly accomplished by Mr. G. W. Bailey, who lives in the vicinity. As this lies in the lacustrine plain before mentioned, it indicates a flow of water around the ice sheet subsequent to the stage in which the lake was formed, a relation which reminds us of what was found in the Red Lake region. Again, a channel extends in T. 98, R. 59,

from Dry Creek to Lone Tree Creek, and the lower course of Dry Creek connects with the mouth of Pony or Twelvemile Creek. By these channels the drainage of the west side of the glacier was effected during the time of the formation of the second moraine, as shown in Pla. XV and XVI.

Wells.—With regard to the structure of the drift formations throughout the area, considerable light has been derived from wells and other excavations. In general, the structure seems to be, as usual, upon glaciated surfaces. First, there is a layer of yellow pebble clay from 10 to 30 feet thick, which passes below insensibly into blue pebble clay, or frequently there is a layer of sand between them.

Along the foot of Turtle Ridge the drift seems unusually thin. The Cretaceous clays are reached within 15 to 20 feet of the surface. Near White Lake the drift is much deeper—more than 50 feet at least. Near White Lake Station several wells of considerable depth were dug, none of them reaching through the drift. The town well was 90 feet deep, most of it being through blue clay. No water had been found when visited. Fragments of wood were found at a depth of nearly 80 feet. One, apparently a root, was over a foot in length and 3 inches in diameter. Generally there is found in that vicinity first 40 feet of yellow clay, then 30 feet of blue clay, then a layer of sand, then blue clay again. Water has not been found except in the yellow clay in basins. At Plankinton there is first usually 75 feet of yellow clay, then 55 feet of blue clay, then chalk or shale containing water. Near Grandview, wells, which are usually dug in basins, are about 10 or 12 feet in depth. A well dug in town upon the hilltop, I was reliably informed, was 150 feet deep and had failed to reach water. All below a few feet of yellow clay at the surface was blue clay. Sixty feet of it was dug, the rest bored. No trace of pebbles was found in the last 10 feet. At Mount Vernon a well 108 feet deep, and containing 52 feet of water, was dug through 40 feet of clay, the rest being chalkstone. This chalkstone appears on the general slope of the country 2 or 3 miles west of Mitchell. It also appears in natural exposures near the general level 10 miles southwest of Mitchell, in ravines connected with Enemy Creek; also near the bottom of the valley of the Firesteel northwest and north of Mitchell, and in a ravine southeast of that place. This chalkstone, which before weathering is bluish, and is then sometimes called soapstone, has been struck in wells 8 miles north of Grandview. At Castalia, on a low bottom of Platt Creek, wells 25 feet deep bring to the surface mostly blue pebbly clay. At Plainview wells 44 feet deep were mostly in blue pebbly clay and furnished poor water. At Emsley post-office, a little west of Plainview, a well was observed about 50 feet in depth, which showed little but pebbly clay and very little water. Several miles southwest of Plainview a well 30 feet in depth showed mostly blue pebbly clay, but at the bottom a thin layer of sand and gravel, below which there was apparently shale.





In the western portion of the region now under consideration traces of wood have been frequently reported as found in wells. Most of them seem likely to be of the sort already mentioned as having been found in the well at White Lake, which probably is a relic of pre-glacial or circumglacial forests.

An ancient tamarack swamp.—Near Grandview, in the southeast quarter of sec. 33, T. 100, R. 64, were found traces of more recent occupation of the region by trees. In a well which had been dug on the edge of a basin near a branch of Andes Creek at the depth of 20 feet was found a layer of muck several inches in thickness, in which were pieces of wood with numerous fresh-water shells of nearly a dozen species. But the most remarkable thing was the stem of a hemlock or tamarack about 10 inches in diameter lying across the well, and in the muck were numerous cones evidently of the same species. Overlying this trace of a tamarack swamp was mud of various colors and consistency, evidently washed from the surrounding hillsides. That it should be so deeply buried was chiefly explained by its connection with the channel of Andes Creek. This was conclusive evidence that the region had been occupied more or less by timber since the ice had covered the region, possibly while the second moraine was in process of formation. Similar finds are reported from wells several miles west of that place.¹

Spotted surface of the country.—One peculiar characteristic of the surface of the country about Plankinton and west is the occurrence of patches of clay spread irregularly in the black loam, which is the usual soil upon the drift, and in this portion still forms most of the surface. These clay patches are very irregular in shape and in depth. In wet weather they are very soft and miry, and in dry weather very hard and frequently seamed with mud cracks. They are usually covered with what is commonly called alkali grass (*Triticum repens*), which in the latter part of the summer is dead, while the blue joint and other grasses upon the loam are still green.

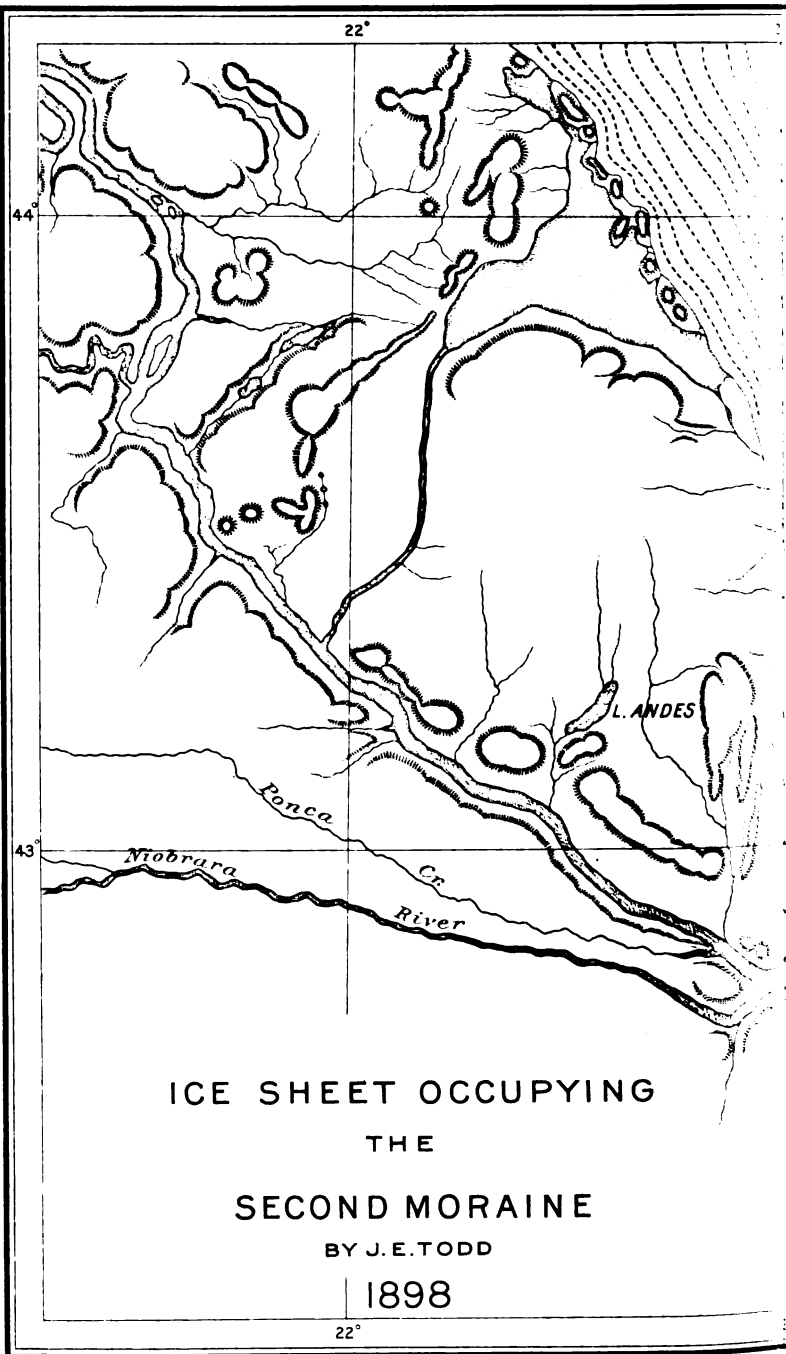
In a few shallow cuts near Plankinton it was noticed that the clay extended in a horizontal direction and that it and the loam were coarsely interstratified. It is possible that this peculiar character of the country is due to its having been occupied by shallow waters from which clay and loam were precipitated somewhat as clay and sand are deposited upon bars along the Missouri at the present time. Another explanation may be found to meet some cases better, viz, that the clay patches are due to masses of Cretaceous clay carried along bodily by the forces of the glacier and deposited as boulders which have afterwards been flattened out. Another and perhaps more probable explanation is that alkaline waters continuing in the depressions have dissolved the silica.

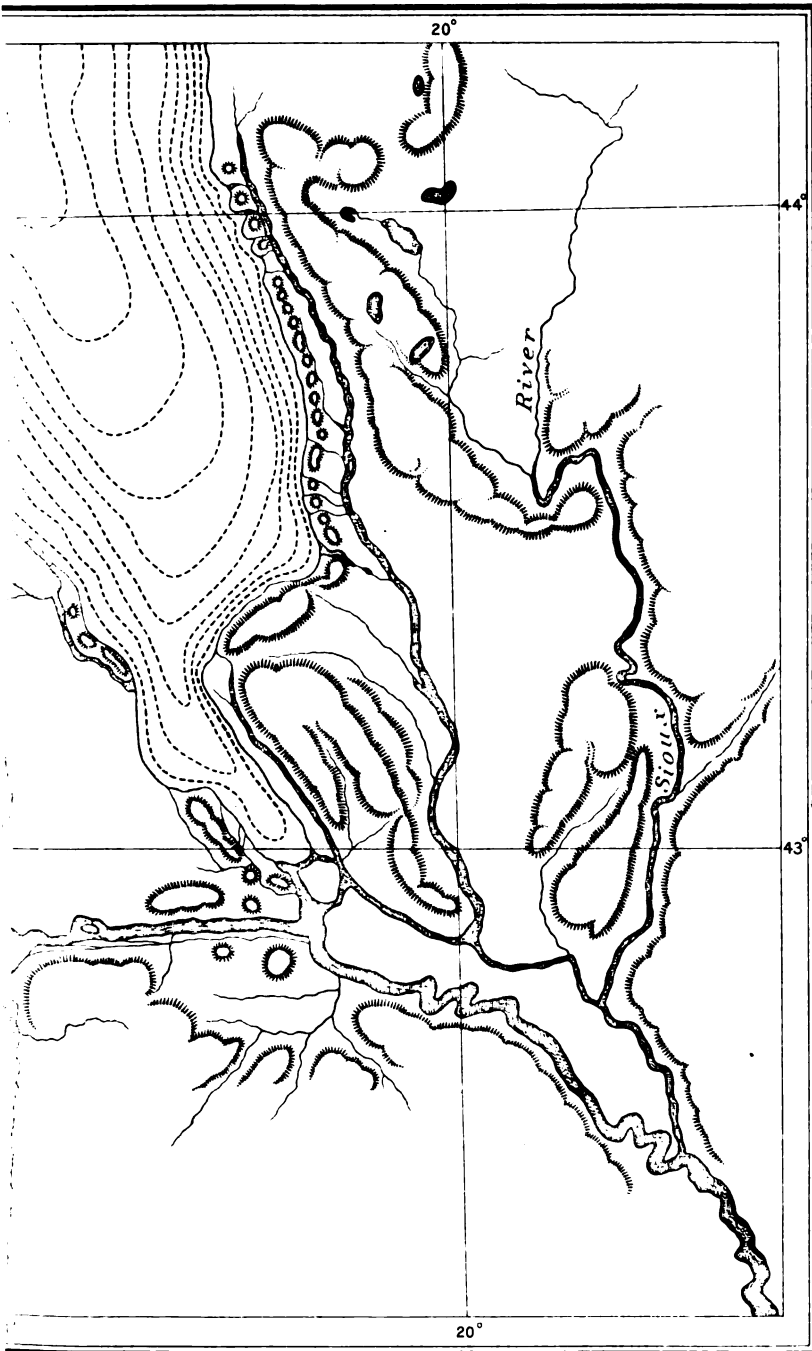
¹ Professor Call determines the fresh-water shells abounding in the muck as follows: *Lymnophyes palustris* Say, *L. decidiosa* Say, *Gyraculus parvus* Say, *Valvata sincera* Say, *Segmentina armigera* Say.

JAMES VALLEY.

This valley occupies the portion between the moraines from the east side of the region already considered to Turkey Ridge, where the two moraines are in contact. The western portion of this region resembles that already described. Perhaps little need be added concerning it. Most of it is nearly level. The exceptions are found near the larger streams and in the vicinity of the principal moraine, particularly near the head of the interlobular portions. We have already noticed the rougher portion, which appears along the eastern rim of the semicircular valley around Choteau Creek Hills. With the rough area near Grandview this may indicate that the ice sheet had a faint tendency to form a moraine between the principal and second moraines. Another somewhat exceptional feature is the occurrence of ponds and lakes in unusual numbers along a line running west from Lesterville for 10 or 12 miles. The principal streams of this region are Emanuel Creek on the west, James River near the center, and Clay Creek on the east. Emanuel Creek, west of Scotland, flows in a wide valley about 50 feet below its eastern rim and at a level higher than the plain a few miles east. Near its mouth it occupies a narrow valley 125 to 150 feet deep. The James River has a valley with abrupt stony sides and from a quarter to half of a mile in width. Its depth at Milltown is about 115 feet; northeast of Scotland, about 150 feet. Clay Creek occupies a broad valley near the moraine, which evidently at one time was the principal outlet from the ice sheet. This valley near the moraine is 50 to 75 feet in depth below the plain northwest. The tributaries of these streams have cut down to the same level near their junctions, and occupy narrow valleys with abrupt sides throughout nearly their whole course. They rise in basins or shallow winding valleys. Through the dry seasons they consist of chains of deep pools, with little or no running water between.

Exposures of older rocks.—Along the James River we discover again many natural exposures of older rocks. The chalkstone of the Niobrara is exposed on the banks of a small stream near Scotland, about 75 feet below the general level. North of Milltown for several miles the Dakota sandstone occupies both banks of the James, rising 40 or 50 feet above the stream. At Rockport is an extensive exposure of Sioux quartzite covering several hundred acres, and just above it, on the east side of the river, there is chalkstone in several localities. Along Enemy Creek both the Dakota sandstone and the red quartzite are exposed, but the latter was too low to be touched by the glacier. The chalkstone shows conspicuously along Clay Creek 120 feet above the stream and about 50 feet above the general level of the plain west. It is also widely exposed along the Firesteel and the channels to the south, including Enemy Creek, as far west as Mount Vernon.





VERMILION VALLEY.

This region resembles the western region in outline, except that its fan-like portion is more extended toward the southeast. Its narrow part, corresponding to the handle of the fan, is occupied by the valley of the East Vermilion. The general slope of the whole surface is toward the southeast. This is indicated by the present direction of the streams, and there is no evidence of a change of course, as in the western portion of the region between the moraines. There is little trace of lacustrine action except along the Lower Vermilion, and this evidently was greater during the recession of the ice than while the second moraine was forming. Along the east side of Turkey Ridge numerous narrow northwest-southeast valleys indicate the action of running water during the earlier recession of the ice. About Swan Lake, in Turner County, occupying an east-west strip 3 or 4 miles in width, is a rough portion showing many low stony hills and ponds. This continues northeastward past Lenox, and may be correlated with the trace of a minor moraine before noticed. The average altitude of this strip is not greater than the country north and south of it. North of Swan Lake, about Turkey Ridge Creek, the country is unusually flat and clayey, forming the broad shallow valley of Turkey Ridge Creek, which is the principal tributary of the Vermilion.

The East Vermilion and Vermilion form the principal stream of this region. The East Vermilion occupies a deep valley just inside the outer moraine. West of Madison it is about 200 feet below the summit of the outer moraine and about 90 feet below the high swell just west of it, which farther south is the second moraine. In its upper portion it displays a very bowldery terrace along the inside of the principal moraine.

Below the mouth of the West Vermilion the stream passes through a broad basin-like valley, perhaps once a lake, till it approaches Turner or Davis, its immediate valley being only 15 to 25 feet deep. Near Turner its channel deepens to 35 feet, is about 50 feet a little north of Lodi, 60 feet at Bloomingdale, and over 80 feet at its mouth. The broad plain along its lower course is very level and even. It extends with similar characters through the principal moraine and terminates as a terrace of the Missouri River.

There is no distinct watershed between the Vermilion and the Big Sioux. The plain reaches through to the Big Sioux without much variation in level. There is probably a very slight slope to the southeast, but railroad levels scarcely show it. The course of the streams in that direction seems more the result of their following back the ice sheet in its recession.

REGION INSIDE THE SECOND MORaine.

This portion of our field has a very even surface. From the inside of the second moraine west of the James the surface extends eastward as almost a dead level to the west side of Miner County, where it begins to rise gradually toward the east, and so continues in that direction to the second moraine on the east. This eastern portion presents the usual topography of slight swells and basins, with the further modification of broad shallow valleys running southward. These are occupied by various branches of the Vermilion and the James. Beginning on the east, we have the West Vermilion River, Wolf Creek, and Redstone Creek.

Upon the level portion of this region the streams take a southwest or southeast direction, as the case may be, to the James River. The whole of this region, except it may be a small portion north of Woonsocket, presents the features of an ancient lake bed filled with drift deposits. Its boundary, so far as yet ascertained, lies close along the inside of the second moraine from the vicinity of Woonsocket to Medicine Hill. This line passes a mile or so west of Letcher, through Mitchell, where, however, it is obscured by knolls, thence curving east and northeast around the foot of Medicine Hill. From that point it curves southeast for a few miles, then around again to the northeast and north, and passes about 2 miles east of Diana, and continues north indefinitely. It seems not improbable that this ancient lake extended as far north as Lake Tchanchicaha. This conclusion is strongly sustained by railroad levels. According to the Chicago, Milwaukee and St. Paul survey the altitude of the station at Mitchell, which is a little below the general level, is 710 feet; Letcher, 713 feet; Mellette, which is 100 miles farther north and again on the level of the lake-like plain, 712 feet; Warren, 713 feet; Aberdeen, 715 feet, while in the region now under consideration, Diana, which is near the eastern boundary of the lake, is 727 feet. These altitudes are above Lake Michigan.

The general surface shows a thin covering of silt, but boulders and pebbles are found a little below the surface. Along the west side of the area there is an old channel, now a marsh called Long Lake, which extends from 2 or 3 miles east of Woonsocket southward to the vicinity of Letcher. Along this marsh and south to Mitchell the surface and subsoil are sandy. Probably this same sandy strip extends northward along Sand Creek, but this has not been ascertained. Around Forestburg, according to report, the sand has collected in well-developed dunes. A portion may be kames. The James River has cut a narrow, sharp-edged valley through this plain. It is 50 feet below the level of the plane near Huron, 60 feet at Forestburg, 75 feet east of Letcher, and 90 feet east of Mitchell.

This lake seems to have been for the most part filled to the level of its surface, but south of Diana (Artesian), and north of Letcher, peculiar

depressions were noticed which may be most readily explained by supposing that the lake at that point was not filled. The surface presents low mounds and broad ridges, irregularly arranged and in some cases isolated, interspersed with shallow marshy basins from 10 to 15 feet below the general level. The mounds between in no case rise above the general level. A ready explanation is that they were at first occupied by ice blocks, while débris from the rapidly melting ice sheet buried them and leveled the general surface. In other words, the region is a "pitted plain," with the "pits" unusually large and confluent.

Flowing wells.—A remarkable feature of the region is the existence of flowing wells in the vicinity of Diana and Forestburg. These are invariably obtained by boring through the till, which is about 100 feet in thickness, to a layer of gravel lying underneath. Sometimes thin layers of sand are struck in the till. The flow is abundant and rises to about 15 feet above the surface at Diana. At all points below that level, as far as has yet been found, flowing wells may be obtained. The most trustworthy and explicit accounts were obtained from Mr. C. J. Croninger, of Diana (now called Artesian). Similar conditions are found near Forestburg, but have not been so carefully examined. At Letcher, also, a flowing well was drilled, but the water was obtained from a much lower stratum, probably the Dakota sandstone. It was at a depth of more than 335 feet. This well was a pioneer of the deep artesian wells that now abound in this region. It was drilled about 1884. A description of the well, furnished by Mr. H. M. Hopkins, who had charge of its boring, is as follows:

Well section at Letcher, South Dakota.

1. Deep soil.
2. Yellow clay.
3. Sand, 1 foot.
4. Blue clay, containing a layer of sand 1 foot thick; this extends to a depth of 100 feet.
5. Gravel and quicksand of several feet.
6. Soapstone, 75 feet, with some slate.
7. Sand rock to the bottom, 335 feet deep.

Cause of Lake Dakota.—The reason why this area was not opened at its southern end so as to prevent the accumulation of a body of water may be traced to the configuration of the bottom when left by the ice sheet, and the failure of the ice to excavate toward the south is readily explained by the extension of the red quartzite across its path. This barrier may be conceived to have so checked the ice as to increase the height of its surface and the erosive action below, just as is the case with a stream in similar circumstances. It would have also increased the velocity of subglacial streams, and in this way may have tended to accumulate masses of gravel. The sandy region along its western side, together with the ancient channel, now a marsh, may be referred to the more recent occupation of that side by the stream, or to the currents flowing through when the lake was filling.

Buried wood.—From several localities reports have come of fragments of wood found in wells. But while suspecting that a deposit of this material might be discovered in the lake, after diligent inquiry in several cases, facts were not found to favor such a conclusion. The fragments were isolated, only a few inches in diameter, and occurred at different depths.

Striæ within the moraine.—The region within the second moraine contains extensive exposures of red quartzite which present in a striking manner the abrading action of the ice. In the following table is presented the more striking observations which have been made. At the westernmost exposure of the red quartzite no striæ have been found, and the occurrence of the Dakota sandstone several feet higher in its close vicinity indicates that it was not subject to the action of the ice.

Striæ found within the second moraine.

[Corrected for magnetic variation.]

Locality.	Direction.
Rockport:	
By the schoolhouse at west side of valley	S. 22°-49°-51°-57° E.
Farther east	N. 89° E. = S. 78° E.
	S. 51°-59°-65° E.
Seven miles north of Alexandria	S. 2°-10°-20°-22° E.
Pier Creek, 5 miles north of Alexandria.	S. 14°-17° E.
Wolf Creek, 6 miles east of last.	S. 8°-12°-17°-22°-29°-32°-37°-42°-49°-57° E.
Wolf Creek, southwest of Bridgewater.	S. 12 W. S. 12°-15°-17°-19°-21°-22°-27°-29°-39° E.

Only one locality is found between the moraines, viz, 2 miles east of Parker, where the direction is S. 52° E.

The exposures in this region are rather extensive, the one at Rockport covering more than a square mile. It affords comparatively few

S

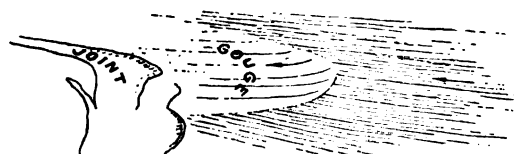


Fig. 30.—A gouge from quartzite exposure, near Bridgewater, South Dakota.

N

striæ, because of its weathered character.

By far the finest locality for its display of distinct and varied striæ is southwest of Bridgewater, where many are several feet in length (Pl. XVII).

They show curves and crooked lines of remarkable form. One was noted 12 feet long, 2 to 3 inches wide, and about one-fourth inch deep. The crescentic cracks are also finely exhibited; a system 18 inches wide and 3 feet



PHOTOGRAPH OF STRIÆ ON QUARTZITE NEAR BRIDGEWATER, SOUTH DAKOTA.

long was noted, and they occur of all sizes from that down to an inch in width. A *roche moutonnée* about 10 feet high and with several nondescript figures pecked upon its surface, stands by the creek near the center of the valley. Toward the westernmost exposure of the quartzite is a peculiar spoonlike gouge in the rock, evidently formed by the ice, at least smoothed and shaped by it. Its edge toward the north is quite complete, sharply defined, and curved like the point of the bowl of a spoon. Its southern edge is lost in the lower surface surrounding. The portion corresponding to the bowl of the spoon is regularly but slightly concave. The outer surface of a surrounding rock rises gently toward the rim before described. The subjoined sketch illustrates it better than words (fig. 30).

CHAPTER V.

TERRACES OF THE MISSOURI AND BIG SIOUX, AND HYDROLOGY OF THE REGION.

These have an important bearing upon the glacial history of the region, as they record more or less clearly the variations in level of streams attending the Glacial epoch and subsequent to it. They form perhaps the clearest evidence attainable in our field concerning the movements of the earth's crust and the meteorological conditions during the epoch. This evidence is the more valuable because it is in great measure independent of glacial deposits.

TERRACES OF THE MISSOURI AND ITS TRIBUTARIES.

These readily arrange themselves in three groups: The silt terraces, the lower bowldery terraces, and the higher bowldery terraces.

SILT TERRACES.

The silt terraces are chiefly distinguished by the fineness of their material and their markedly lower elevation. They do not rise anywhere higher than 100 feet above the present stream, and are usually much lower. Although covered with silt, they are not entirely composed of it, but often—especially the higher ones—are composed largely of Cretaceous clays in situ.

The survey of this group of terraces has been necessarily very incomplete. The number of observations taken is far from sufficient to prepare the way for a thorough discussion of them. The attention of the writer has been more turned to the bowldery terraces, which are more intimately connected with glacial phenomena. In general it may be said that there are two silt terraces which lie above high-water mark of the present time and which may be traced at most points favorable for their preservation. The difficulty of correlating them arises from their higher elevations in the vicinity of tributaries and the occasional interpolation of subordinate terraces.

At the Great Bend (Pl. XVIII) the higher terrace upon the right side of the river lies from 90 to 100 feet above low water. It is extensively developed in the bend; in fact, with the lower silt terraces it occupies the whole area of the bend north of its neck. This bend describes a circuit of 30 miles, returning to about $2\frac{1}{2}$ miles from its beginning. At this locality is well illustrated the principle that a continually cutting stream forms a slope on the inside of a bend, which shows no break



GREAT BEND OF THE MISSOURI RIVER FROM THE EAST.

vvv A neck of Pierre clays, which, if cut through, would shorten the river 20 miles. v Missouri River. vv Bowldery terrace.

unless the course of the stream is at some point turned against it. Hence we find that this upper terrace grades down insensibly to the lower terrace in this slope, which is 7 or 8 miles in length. On the eastern side of the neck, where the measurements already given were taken, the lower silt terrace is from 30 to 70 feet higher than the river, while the present flood plain is only 10 to 18 feet above. On the opposite side of the river the higher terrace extends as a plain from 2 to 3 miles in width from the Great Bend to Crow Creek Agency and beyond. Its elevation above the river at the upper end is from 90 to 108 feet. Near Crow Creek Agency, where Soldier Creek enters from the northeast, it is from nearly 110 to 200 feet, while the bottom lands upon which the agency buildings are located is about 15 feet above the river.

At Chamberlain the lower terrace, upon which the town is built, is well represented, and shows, away from the mouth of American Creek, the Niobrara chalkstone occupying most of its height. It slopes from about 70 to 50 feet. Along its outer edge are a series of short, sandy spurs which rise to 125 feet. They may be part of a delta of American Creek. The lower terrace is narrowly developed along American Creek. Across the river, above Chamberlain, we again find the higher terrace well developed, from 40 to 70 feet in height, and traces of lower terraces also occur.

At Lower Brule Agency a lower terrace, about 45 feet in height, is well developed, the upper terrace being traceable also north of American Crow Creek, and back and south of the agency it is from 60 to 70 feet in height. Lower than the terrace upon which the agency is situated is a narrow flood plain, covered at high water. The higher terrace may be traced down the river as follows: It is faintly developed below the mouth of White River at an elevation of 50 feet. Opposite Brick Kiln Buttes it is narrowly developed and is about 80 feet high. Below the mouth of Snake Creek a high terrace appears sloping from a rather indistinct line about 150 feet above the river down to 50 feet, where it ends in a conspicuous edge. This is probably to be attributed to the rapid cutting down of the lower bowldery terrace through the narrows above Wheeler. At Mill Head Point, about 10 miles above Wheeler and on the opposite side of the river, it is about 75 feet in height. It is traceable north upon the opposite side of the river, and 2 or 3 miles south on the same side. At Wheeler there is a terrace upon which the town is built, about 45 feet above the river. The fine terrace upon which Fort Randall is built is from 30 to 35 feet above the river. At Niobrara the new town is built upon an extensive terrace about 25 feet above the river. No purely silt terraces higher than from 15 to 20 feet are noticed along the river farther south.

The lower terrace is represented again west of Brick Kiln Buttes at 30 feet and at the same level at Rosebud Landing. Below the mouth of Snake Creek it is not represented, unless in a broad bottom sloping from

about 25 feet down to about 10 feet. At Mill Head Point it is sharply shown at 45 feet. At Wheeler a terrace of considerable width rises about 18 feet and continues some distance eastward along the north bank of the river. A similar terrace, though narrowly developed, rises about 15 feet at Fort Randall, and is much wider on the opposite side of the river at White Swan. Farther down this seems to disappear or to be indistinguishable from the flood plain, which at Niobrara rises from 10 to 15 feet above the river, and about the same height farther down. This lower terrace is almost purely sand and dark loam; the higher terrace, as before stated, frequently has a Oretaceous base, and at some points, as at Wheeler and Fort Randall, considerable gravel and boulders are found in its lower portion.

LOWER BOWLDERY TERRACES.

Just north of the narrowest portion of the Great Bend rises a high, broad, butte-like hill. To the north it is bounded by the silt terrace already described. At the south a low ragged ridge of Oretaceous clays connects it with the main bank. Its surface, where least eroded, is quite even. It rises 235 feet above the river. Its whole upper surface is covered with boulders and gravel mixed with yellow clay.

With a glass the hills to the northwest across the river were discovered to be also boulder clad. Upon the east side of the bend the highland, curving sharply up against the river, shows no drift. No trace of bowldery hills similar to the one described is found till Soldier Creek is crossed, north of Crow Creek Agency. There a range begins which extends southeast across Campbells and Elm creeks to the vicinity of Crow Creek. These hills are more or less detached from the highlands north by erosion. East of Campbells Creek they rise to 320 feet above the river. A well-defined bowldery terrace was noticed along Boxelder Creek 12 miles farther east, rising to the height of 125 feet above the stream. It is estimated to be 15 or 25 feet above the bowldery terrace east of Campbells Creek. South of that point this terrace is remarkably developed about the junction of Boxelder Creek with Crow Creek. It was also examined between the lower courses of Crow and Smith creeks, where it is mostly a barren plain of gravel.

In the vicinity of Chamberlain the extensive series of old channels and terraces which have been noticed in our consideration of the Red Lake region are found at a height of 200 feet above the river. This includes an old channel cutting across the northwest corner of T. 103, R. 71, leaving an ancient island west of it, and also the channel from American Creek southwest to the Missouri, in which lies Red Lake, (Pl. XV). At about the same level is a broad, well-developed terrace lying along the north bank of the Missouri for 2 or 3 miles above its junction with White River. Along American Creek above Pukwana is an old lake bed at the same altitude, which is probably a portion of the old Red Lake channel. The terraces and channels show much gravel in

their upper portion, though covered with 10 or 15 feet of loess-like silt. An imperfect exposure in a ravine northeast of Ancient Island before mentioned, which is opposite Lower Brule Agency, is as follows:

Exposure northeast of Ancient Island, South Dakota.

	Ft.	In.
Gravel and sand, horizontally stratified	8	0
Laminated clay, showing ripple marks	1	2
Gravel and sand, arranged in short crescentic patches, showing oblique stratification (torrential)	10	0

This exposure is about 50 feet below the bottom of the old valley, and does not, therefore, include the covering of silt observed elsewhere.

In the vicinity of Chamberlain, also, the prevalent altitude of the bluffs along the river is from 325 to 350 feet. Their tops are quite uniform and little eroded. They are capped with 40 to 50 feet of drift, which passes into a layer of loess probably from 5 to 15 feet in thickness. The bluffs, across the river especially, have the appearance of a terrace. North of American Crow Creek a bed of gravel was found capping the edge of the terrace-like bluff 315 feet above the Missouri. It corresponds in level to the gravelly drift already mentioned as quite extensive on the south side of that stream. The top of Ancient Island, opposite Lower Brule Agency, rises 300 feet above the river. Between the lower course of the White River and the Missouri extends a silt-covered plain which averages about the same elevation. A terrace occupying the first bend in the Missouri to the south, and also a portion of the second in the same direction, is estimated to be at the same altitude. The lower gravelly plain south of White River seems to be only a little more elevated (350 to 400 feet), and probably belongs to the same formation. Perhaps some of it is a little more ancient.

Along the narrow channel directly southwest of the Bijou Hills I failed to observe any trace of this terrace, but west and northwest, back of the silt terrace already mentioned, it is widely developed as a sloping terrace from 95 to 175 feet high. It presents the usual features of 10 or 15 feet of loess-like silt above a heavy deposit of bowlders and gravel. In the valley of Pratt Creek, near its mouth, and developed extensively along the Missouri, is a boulder-topped terrace 330 to 360 feet above the latter. A view of it from the south led to the belief that it was originally connected with a high terrace at Mill Head Point, which rises 250 feet above the river and rapidly declines toward the south. This latter terrace exhibits a remarkable quantity of bowlders in its upper portion, the coarseness of material apparently diminishing down the stream. Its structure is finely shown by a ravine crossing it a little below Mill Head Point. Its upper surface was originally covered with 10 to 15 feet of loess-like silt, which has been removed near the edges and along the ravines.

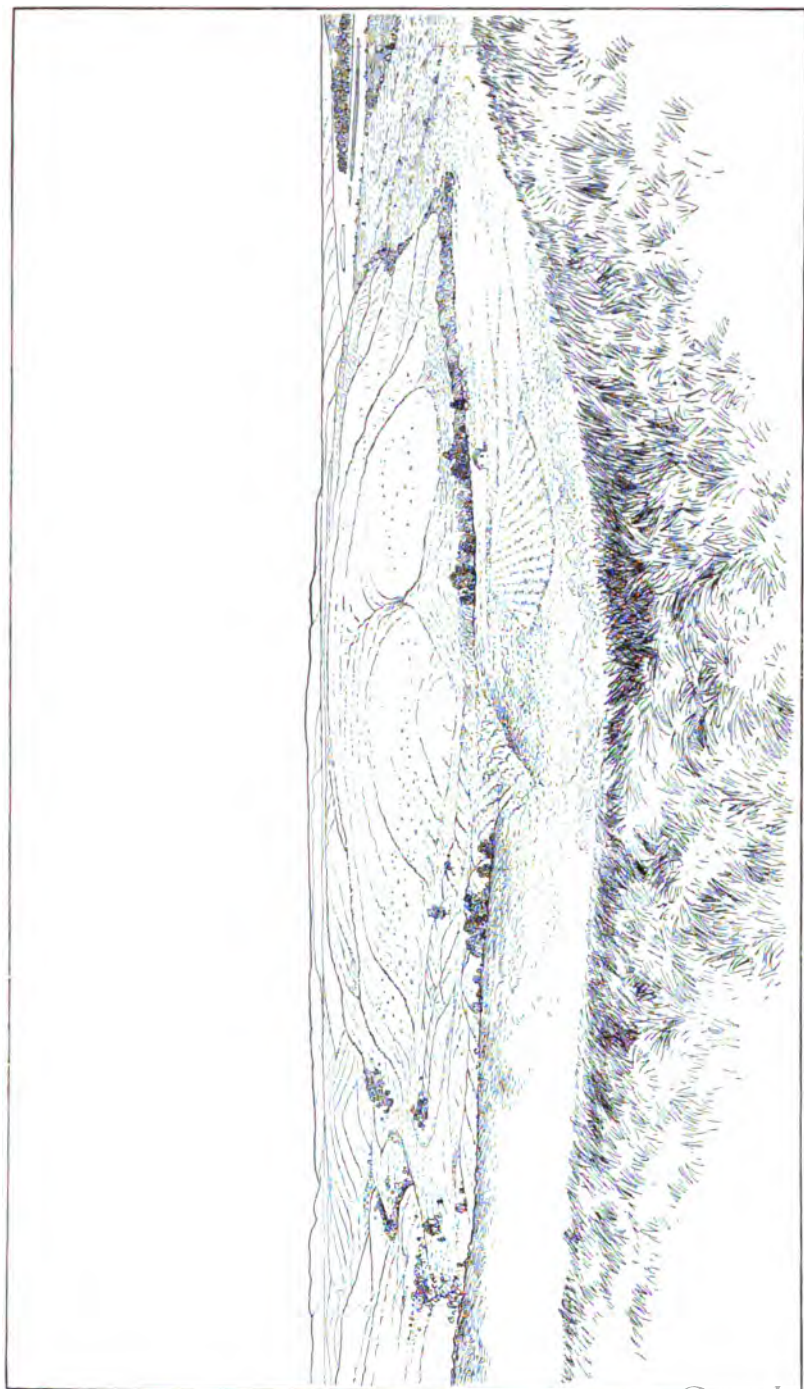
At Mill Head Point there is an extensive boulder bar, reaching well out into the river, which at that point runs like a mill race. I was

informed that the river survey developed the fact that the river about 2 miles north of Wheeler was paved with boulders.

Back of Wheeler is a broad terrace rising at its southern edge about 150 feet above the river. This presents a deep gravel bed, with boulders in its upper portion and covered with loess-like silt about 10 or 15 feet in depth. North of Fort Randall, at the junction of the Andes Lake Outlet with the Missouri, a broad, sloping terrace lies at an altitude of 120 feet at its inner edge (Pl. XIX). Farther back it connects with the mouth of Andes Lake Outlet at the altitude of 200 feet. In this terrace the Cretaceous shales rise to the height of 90 feet. At Greenwood the terrace upon the north side of the river at its edge rises to an altitude of about 180 feet, presenting characters similar to those already mentioned. This terrace continues, with a breadth of from 2 to 4 miles, along the north side of the Missouri to the mouth of Choteau Creek. It presents a beautiful fertile plain, quite even except where traversed by the three or four creeks which flow in deep, narrow valleys. The edge of the terrace back of Greenwood is 175 feet high; east of the creek near by, 140 feet, and 6 or 7 miles east in a similar locality, 200 feet. The remote edge of the plain east of Grass Lake Outlet is 240 feet, and about 5 miles northeast of Greenwood, where the ancient bank rises abruptly 75 feet above it, it is 250 feet above the river to the south (Pl. XX). North of Running Water this terrace fills the bend in the Missouri from the mouth of the Niobrara to Springfield, with an altitude quite uniformly of 200 feet. It constitutes the first bench north of the town of Niobrara, more than a mile in width, and is continued up the Niobrara River, first in the sharp south bend near its mouth, then extensively on the south side of the river up for 15 or 20 miles. This terrace is also well developed along the east side of Bazile Creek.

Farther east, along the south side of the Missouri, the surface has been so modified by erosion that little trace of terrace formation could be expected and none was noticed. In the valley of Weigandt Creek southeast of Herrick, Nebraska, there is an extensive terraced surface rising at some points about 325 feet above the Missouri. There was much difficulty, when first examined, in correlating it with other deposits along the Missouri. But further study led to the satisfactory conclusion that it was formed by Weigandt Creek and its tributaries. It rises from 175 to 200 feet above that stream. It presents the usual features of a gravelly terrace, with the silt covering scantily formed. Similar deposits are found along the neighboring stream, called Beaver Creek.

At Yankton, on the north side of the river, the outer slope of the moraine, as was noticed in the valley northwest of the town, is quite gravelly about 130 feet above the river. Passing north from Yankton 3 or 4 miles, we reach a broad terrace south of another of the numerous Beaver creeks. This is at an altitude of 120 feet above the river and connects with the broad valley south of Lesterville. Though the



LOWER BOWLDERY TERRACE, OPPOSITE FORT RANDALL.

terrace seems mostly covered with pebble clay or loess-like silt, on the slope south of Utica considerable gravel was noticed.

At Vermilion the principal terrace, which is 6 or 7 miles wide and extends eastward to the Big Sioux, is about 80 feet above the river. It shows its structure to be pebble clay, with its upper surface eroded and capped with silt.

Below the mouth of Floyd River, near Sioux City, is a terrace 115 to 150 feet high. It is composed of coarse sand below and of loess-like silt in the upper two-thirds; no boulders.

In the vicinity of Herman, Nebraska, a terrace begins which continues past Blair to De Soto, about 10 miles in length and in places nearly 2 miles in breadth. This rises 100 feet above the river. At Fort Calhoun a similar terrace extends 5 or 6 miles. An obscure one about 60 feet in height is found at Omaha. At Bellevue, north of the mouth of the Papillion River, is another well-developed terrace from 60 to 70 feet above the river, and a similar one is found below the mouth of the Weeping Water at Wyoming.

We have already briefly described the extensive terraces along the Platte and Elkhorn rivers which rise to a level of 80 feet near their junction.

The valley of the White River approaches that of the Missouri in size, and is likewise mostly excavated from the Cretaceous clays. The alluvial bottoms rising about 20 feet from the bottom of the river form a more prominent feature, usually occupying most of the space in the deep bends in the river. Rising abruptly from this alluvial plain are bluffs of shaly clay over 100 feet in height. At an altitude of about 130 feet is a well-defined gravelly terrace containing mostly western gravel. This seems to be excavated out of the Cretaceous, which appears again back of it and rises abruptly to the edge of a higher terrace about 200 feet above the stream. This terrace in one place shows alluvial deposits 30 or 40 feet in depth, exhibiting loess-like silt below, including about its middle a dark carbonaceous layer like an old soil. It is capped above, first with gravel, then with bowldery clay, which slopes with a gentle rise backward from the river to a height of about 260 feet. At the height of about 325 feet another gravelly terrace appears, containing northern erratics and limestone and granite bowlders like the last. This seems to be continuous with the sheet of gravel south of the river, which has already been described.

COMPOSITION OF LOWER BOWLDERY TERRACES.

Thus far we have treated only of the external appearances of the lower bowldery terraces. We now proceed to give what light has been found concerning their internal structure and composition. There has already been given an imperfect section, which is found opposite the Lower Brule Agency. Apparently, although not certainly, the pre-

vailing structure is somewhat as follows: Ten to 15 feet of silt, passing abruptly into stratified sand and gravel, which is coarse and bowldery near the top, and finer and more evenly stratified below, the depth of the sand corresponding to the inequalities of the deposits below. In some cases the upper portion of the gravel is more or less occupied with till of reddish or yellowish color.

At White Swan and below, the Niobrara chalkstone and Pierre clays rise over 100 feet, forming a very substantial base for the terrace. Above these there seems to be a heavy body of till, but it is nowhere well exposed. Seven miles east of Greenwood the Cretaceous clays appear to rise over 150 feet, and shallow exposures exhibit red till above for 30 or 40 feet, and a mantle of silt of variable thickness over the whole. Between that point and the mouth of Choteau Creek the terrace is much eroded, but little or no trace of sand is found. The phenomena of soil and topography seem best explained by supposing that the body of the terrace is largely composed of Pierre clay.

Opposite Niobrara is a very complete exposure of the terrace, which is as follows:

Exposure opposite Niobrara, Nebraska.

	Feet.
Loess-like silt.....	10-12
Red clay, imperfectly stratified, which abounds in pebbles and bowlders.....	35
Fine sand, thinly stratified, with no trace of northern erratics.....	55
Imperfectly exposed	45
Niobrara chalkstone	70
Level of the river.	

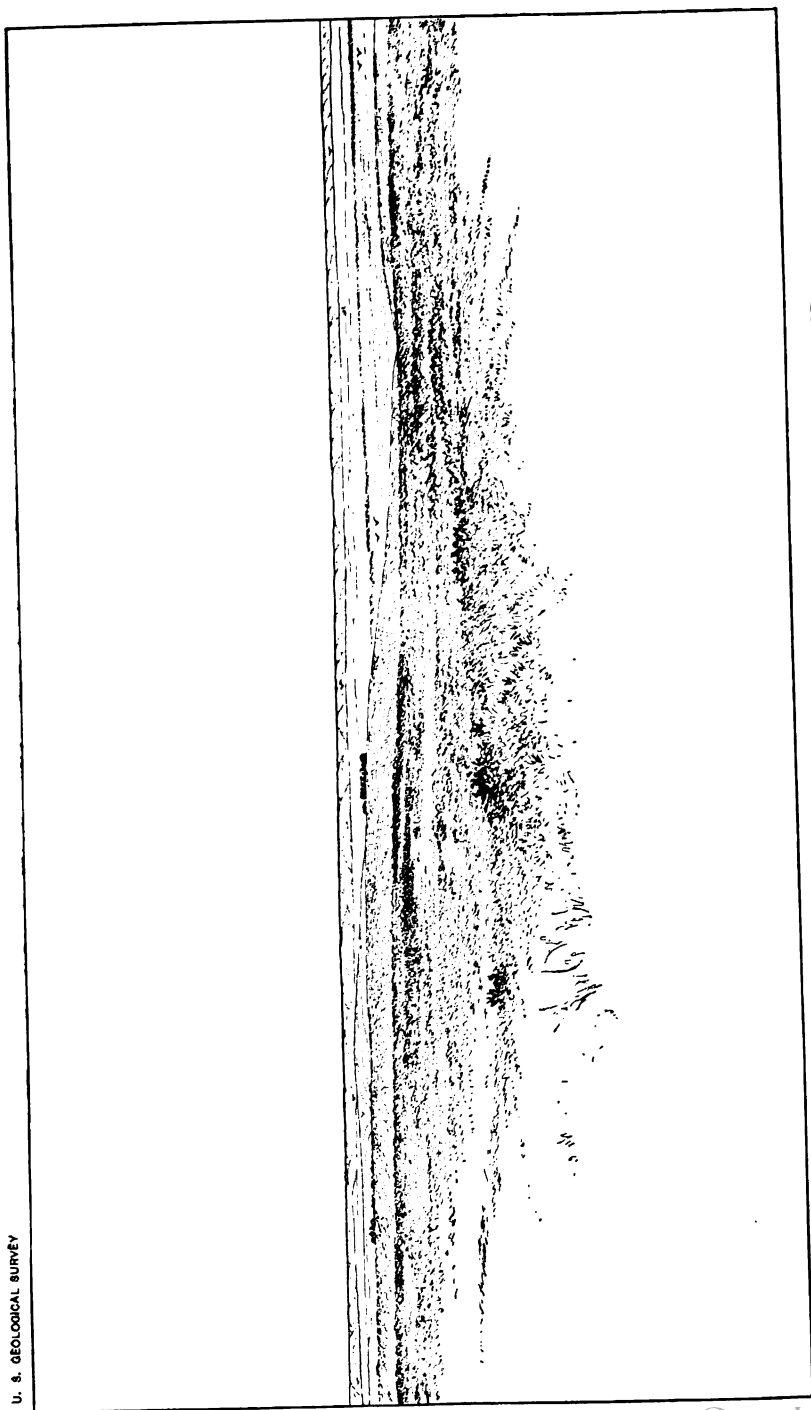
The sand in this section seems identical in structure and composition with that observed at the Devils Nest and north of Coleridge. While there it is at an altitude of from 350 to 400 feet above the river, here it is below 150 feet. Still, its freedom from northern erratics would seem to indicate its pre-Glacial deposition. Moreover, it has less altitude than the Cretaceous rocks in this same terrace farther west, and the red clay at this point seems to correspond to that at Greenwood, both in altitude and in time of deposition. On the whole, therefore, it seems not improbable that the sand was deposited by the Niobrara, possibly in Lake Cheyenne, before the advent of the drift.

At Vermilion a combined section is as follows:

Section at Vermilion, South Dakota.

	Feet.
Loess-like silt, straticulate.....	15-20
Till, eroded on top, yellow and compact above, and composed of irregular patches of gravel, sand, and red and blue till below.....	40-50
Unexposed	20
Level of the river.	

This composition may be referred to material brought down by the Vermilion River, at first laden with ice blocks, or in part to the direct action of the extension of the Vermilion lobe of the ice sheet. On either supposition a deep preglacial valley at this point must be postulated.



LOWER BOWLDERY TERRACE, FROM THE OLD BANK NORTH OF GREENWOOD, SOUTH DAKOTA
v v Broad, shallow, channel-like slough.
v Missouri River.

Three miles southeast of Blair the structure of the terrace is finely exposed in a number of deep ravines which cut through two-thirds of its height. They show nothing but rearranged loess, with an occasional thin streak of gravel in its lower portion. A similar composition is evidently true of the terrace at Fort Calhoun and also at Bellevue, except that its base is occupied by Carboniferous limestone. In each case the composition is referred to the numerous high loess bluffs in the close vicinity and along the river above, with comparative absence of drift.

The terraces along the Platte and Elkhorn have apparently very uniform structure, which consists first of silt, then of fine sand, passing below into fine sand and gravel. The evidence from deep driven wells shows that below the first gravel is a thick continuous layer of clay, below which is another heavy deposit of gravel. These lower layers extend underneath the whole valley so far as is known. Northwest of Fremont an exposure showed as follows:

Exposure northwest of Fremont, Nebraska.

	Feet.
Loess-like silt	30-40
Fine sand.....	30-40
Unexposed.....	20
Level of bottom land, which is probably 10 to 20 feet above the level of the river.	

North of North Bend was found from 5 to 15 feet of silt, according to the undulations of the surface, and sand rising from 75 to 80 feet above the river. The upper surface of the terrace shows gouges and imperfect channels, as if formed by strong currents.

From the foregoing presentation, particularly if reference is made to the table on a subsequent page, it appears that, above the narrows above Wheeler, there are two series of terraces mentioned under this head, one 100 to 150 feet above the other; also, that they come together below Wheeler. That they do not mark stages of the river as widely separated as their altitudes might seem to indicate may be inferred from the following considerations: The lower seems in places to be continuous with the bottom of old channels, as that of Red Lake, and east of Ancient Island, as though it corresponded to the bottom of a stream, while the upper series seems to slope gradually up into the surrounding country, as though it might mark the margin or flood plain of the ancient stream.

HIGHER BOWLDERY TERRACES.

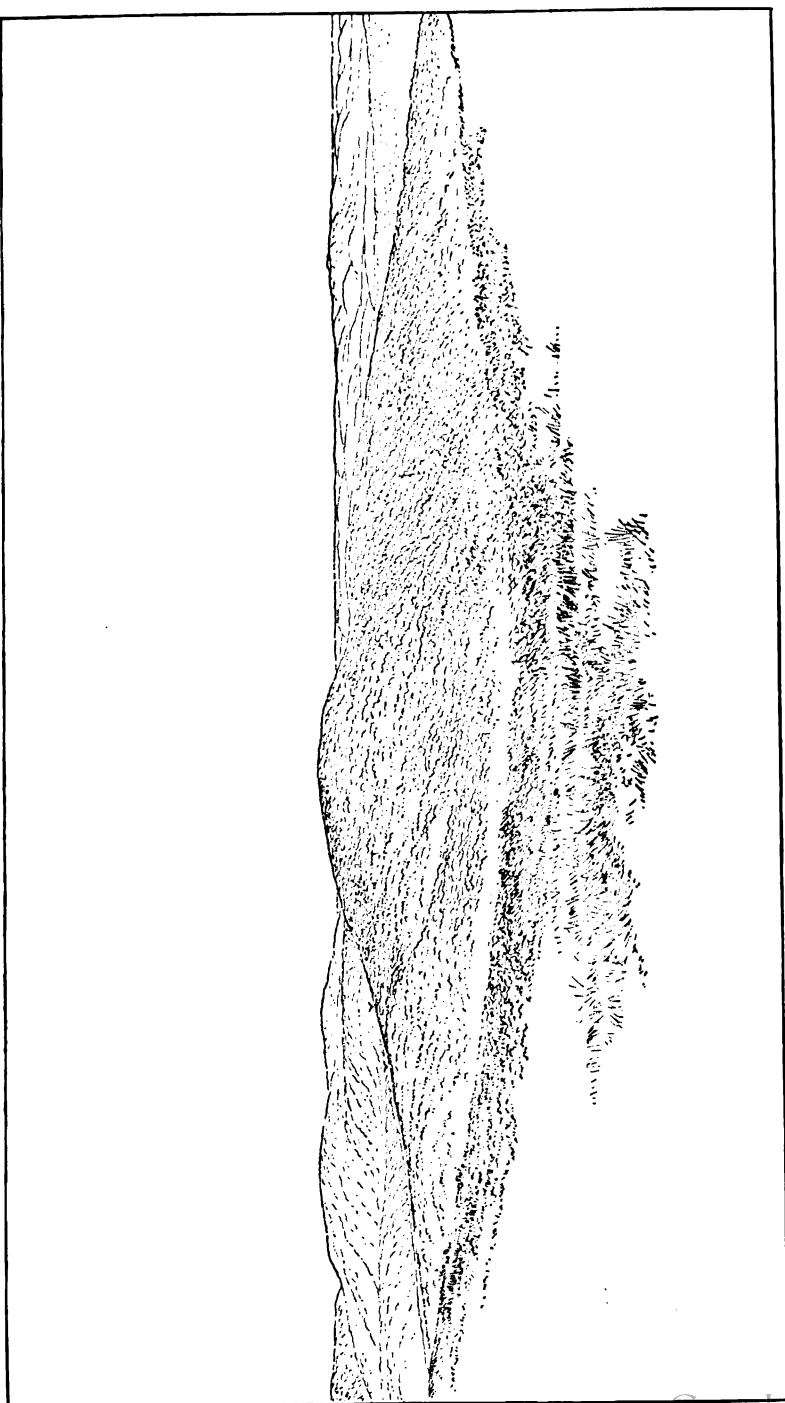
These are the least easily recognized of all. This is not surprising when we remember that they are much the most ancient. Their high elevation, together with the unusually loose character of the strata upon which they rest, lead to the same result. Moreover, if the river was largely lacustrine when they were formed, as we are disposed to believe, its existence will only occasionally be evidenced by deposits adjacent to the present stream. They may have the various forms of

beach or bar and delta as well as river terrace, according to circumstances. Little time has been given to their study, and the few observations incidentally made are given for what they may be worth.

Near the summit of the high hill south of the Red Lake Outlet, on the side next to the Missouri, gravelly deposits were noticed at the altitude of a little more than 425 feet, which may be correlated with the higher portion of the gravelly plain just mentioned. Along Snake Creek, near its mouth, an extensive sloping terrace is found, with its usual bowldery gravel covered with silt and rising 330 to 417 feet above the river. Besides these in the Red Lake region, we have nothing to suggest a terrace deposit below the trace of a water level around the Bijou Hills and the bowldery and gravel-topped hills 5 or 6 miles southwest of the mouth of White River, which are believed to mark the highest reach of the Missouri since its beginning.

Five or 6 miles east of Wheeler the outer face of the moraine shows, at the different points, the gravelly edge of a terrace at an altitude of over 400 feet. At Fort Randall, on the south side of the river, is a well-defined terrace, with its inner edge having an altitude of 415 feet. Northeast of Fort Randall, near the moraine, is a similar well-defined edge of a terrace 420 feet above the river, which slopes gently up to 450 feet. On the north side of the river northeast of Greenwood the surface is too low to exhibit any trace of a water line at this level. Opposite the mouth of the Niobrara the outer surface of the hill which forms a fragment of the moraine shows, a little below the summit, abundant gravel and sand at an altitude of about 400 feet above the river.

Between the Niobrara and Bazile Creek and along the Missouri east of the Bazile is found a wonderful development of gravel capping the older deposits in a terrace-like form at an altitude of 415 to 475 feet above the river (Pl. XXI). It is observed to extend several miles south, and, as has been described under the head of the loess region, there is abundant evidence to show that this gravel formation extends underneath the loess indefinitely. It may not be called a terrace, yet the gravel exposed along the north edge of the loess, between it and the fine sand below, seems probably to belong for the most part or entirely to the same formation as the terrace described. Toward the east side of the Santee Reservation the gravel seems to have been separated into an upper and a lower member. The lower portion extends like an eroded terrace at the height of 390 feet. We have provisionally ascribed this phenomenon, on another page, to undermining. It will be remembered that this gravelly drift extends, with declining elevation, nearly to Dixon County. So far as has yet been discovered no trace of terrace at a corresponding altitude has been noticed below that point. It corresponds in elevation with gravel beds observed several miles up the Niobrara and with another near Plainview, Nebraska. Both of these show only western gravel.



UPPER BOWLDERY TERRACE SOUTHWEST OF SANTEE AGENCY, NEBRASKA.

v Volcanic ashes in road.

Table of heights of the terraces along the Missouri from the Great Bend southward.[*r* indicates the right bank, and *l* the left.]

Locality.	Silt terraces.	Lower bowl- dery terraces.	Higher bowl- dery terraces.
	<i>Feet.</i>	<i>Feet.</i>	<i>Feet.</i>
In the Great Bend <i>r</i>	10, 18, 30-70, 90-100	235	.....
East of the Great Bend <i>r</i>	90-100	.....	.....
Crow Creek Agency <i>l</i>	15, 110-150	200-250, 320	.....
Two miles above Chamberlain <i>r</i>	8-10, 30-70	325	.....
Chamberlain.....	15-30, 50-80, 120-125	325	.....
Three miles south of Chamber- lain <i>l</i>	75-80	200, 350	.....
North of American Crow Creek <i>r</i>	<i>a</i> 70-80	315-320	.....
Lower Brule Agency <i>r</i>	10, 20-40, 60-70	.....	.....
Ancient Island <i>l</i>.....	.....	200, 300	.....
Above mouth of White River <i>r</i>	<i>a</i> 50	300	.....
South of mouth of White River <i>r</i>	<i>a</i> 10	250	350-400 510
South of Red Lake Outlet <i>l</i>.....	.....	<i>a</i> 200	450-460
West of Brick Kiln Butter.....	15, 30-50	90-175	.....
Bijou Hills <i>l</i>.....	.....	.....	590
Rose Bud Landing <i>r</i>	15-20, 65-75	.....	.....
Near mouth of Snake Creek <i>l</i>	10, 20, 50-150	330	417
Near mouth of Pratt Creek <i>l</i>	90-126	300-350	.....
Mill Head Point <i>r</i>	45, 85	200-250	.....
Wheeler <i>l</i>	5, 9-18, 45, 85-105	<i>a</i> 135-175	.....
Four miles east of Wheeler <i>l</i>	40-75	.....	410-430
Andes Outlet <i>l</i>	<i>a</i> 10, 25	125-190	350
Fort Randall <i>r</i>	15, 30, 40-45	.....	415
Greenwood <i>r</i>.....	.....	180-240	.....
6 miles east of Greenwood <i>l</i>.....	.....	200-250	.....
Opposite Niobrara <i>l</i>.....	.....	200	<i>a</i> 400
Niobrara <i>r</i>	5, 10, 20	180-210	415-450
Devils Nest <i>l</i>	10, 30	.....	450-475
Yankton <i>r</i>	10, 25, 70	120-140	.....
Vermilion <i>l</i>	10-15, 20-25	80-100	.....
Blair <i>r</i>	10-20	90-110	.....
Calhoun <i>r</i>	<i>a</i> 10	<i>a</i> 100	.....
Bellevue.....	<i>a</i> 10, 20	50-70	.....

a Estimated.

The different levels under the head of "lower bowldery terraces" probably do not mark two stages of the Missouri, widely separated, as might be inferred, for the upper one appears to have been marking generally the surface or flood plain of the river, while the lower in many cases seems from its configuration in some places to record the bottom of the stream.

TERRACES ALONG THE BIG SIOUX.

As the Big Sioux is the counterpart of the Missouri in its relation to the moraine, so we should reasonably expect a system of terraces along it resembling that already described along the Missouri. From its lower altitude, more open valley, and less volume of water, we are prepared to anticipate lower floods and less corrosion, and consequently less difference in altitude between the terraces. Another important circumstance acting in the same direction is found in the greater hardness of rocks over which it flows. But without anticipating too much, we will proceed to examine the few traces of terraces which have been noted. It should also be acknowledged that the examination of this stream has not been so complete as in the case of the Missouri.

Above Sioux Falls the depth of the immediate valley of the Big Sioux is from 80 to 100 feet below the adjoining hills. Its sides are less abrupt, and the whole appearance is that of a stream in its middle course. This may be explained by the check given to its erosion by the ledge of Sioux Falls and higher up by the rock at Dell Rapids.

SILT AND LOWER BOWLDERY TERRACES.

At Egan, besides the immediate flood plain, which is quite low, is a terrace along the north side of the valley with its inner edge about 30 feet above the stream. About a mile and a half northeast of Egan, in the edge of a gravelly terrace, the following section was noticed, beginning 30 feet above the river:

Section northeast of Egan, South Dakota.

	Feet.
Soil	1½
Loess-like clay, with small pebbles and chalky points	1
Roughly and indistinctly stratified gravel, its upper half clayey, yellowish tint; lower, more sandy	7½
Coarse sand, with scattered pebbles, obliquely stratified, in eight layers from 1 to 8 inches in thickness	5½

At Sioux Falls, as has been before stated, there is a very gravelly terrace extending from near the top of the falls down the river to the vicinity of Brandon, which is shown by railroad levels to be about 80 feet above the stream at that point. A little below the mouth of Split Rock River the elevation of the wide bottom along the east side of the Big Sioux is from 35 to 50 feet above the stream. Its altitude here is possibly due to ledges of red quartzite exposed a short distance below. At Kruger's mill, about 6 miles northeast of Canton, the terrace lies on both sides, but best developed on the east side, about 50 feet above the stream, and presents an interesting deposit of sand and gravel in its upper portion. The gravel presents the flow-and-plunge structure, and through it a fault was noted of a few inches throw extending vertically. At Canton several alluvial terrace edges are shown along the sides of



DIG SIOUX RIVER NEAR FAIRVIEW, SOUTH DAKOTA.

v Principal moraine. v Plain inside. v v Higher bowldery terrace. w Lower bowldery terrace.

the valley. There are but two, however, that are clearly distinct; the first is from 10 to 20 feet above the stream, the second about 40 feet. The edge of the plain northwest shows a terrace edge, usually with much gravel at exposed points. This is about 125 feet above the stream.

In the narrow portion of the valley between Beloit and Fairview (Pl. XXII) is found a very interesting terrace of unusually bowldery character, which seems to correspond with the plain northwest and just north of the north end of the moraine, which occupies Highland Township. This plain, it will be remembered, corresponds in height with, or is a continuation of, the plain west of Canton, upon which Worthing and Lenox are situated. This terrace, 2 miles northwest of Fairview, is about 90 feet above the stream, and presents a furrowed appearance, as though eroded by streams flowing in the same direction as the present stream. These furrows and low places correspond with a second terrace, which is about 45 feet above the river. Opposite Fairview the whole surface has declined to that altitude. Back of Fairview a faint terrace edge was noticed at a height of 50 feet. Northeast of Austin this same high terrace is traced, presenting similar characters, at an altitude of 60 to 75 feet above the stream. Just north of Hudson, on the west side of the Big Sioux, is a gravelly terrace utilized by the railroad company as a gravel bed. Its upper surface is about 60 feet above the stream. The surface of this terrace appears to decline rapidly toward the south. It is not difficult to correlate this series of terraces with the lower bowldery terraces along the Missouri. A well-developed gravelly terrace is found on the south side of the valley above Lake Madison, rising about 80 feet above the lake, and along east of Skunk Creek, southwest of Dell Rapids, a terrace, apparently of silt, rises to the height of 40 feet.

HIGHER BOWLDERY TERRACES.

The first and most remarkable examples of these are the high gravel hills northeast of Sioux Falls which, as was stated on a preceding page, rise about 210 feet above the stream. Near Kruger's mill, it will be remembered, there is a high terrace, with its inner edge about 160 feet in height, while farther south an exposure showed a stratified structure like that of a terrace at the height of 108 feet, and a gravelly line at a height of 180 feet. West of the stream a very bowldery edge, like that of a terrace, was noticed at a height of 120 feet, which is a little above the plain west. East of Canton the gravelly deposits shown in railroad cuts extended from about 100 to 175 feet above the stream. North of Fairview, and also east of the same place, a gravelly edge appears on the side of the bluffs at the height of from 200 to 220 feet. West of Oalliope the hilltops, which are doubtfully referred to a terrace, are about 125 feet above the stream.

TERRACES ALONG OTHER STREAMS.

There are few other streams in the field under consideration which are outside of the moraine. Those of this class in Iowa have not been studied with care, but most of them show high terraces of silt—second bottoms, as they are popularly called—which often serve as favorable locations for towns.

Striking examples of prominent terraces corresponding to those along the Platte and the Missouri below Sioux City have been noted along the Boyer at Dunlap and Logan, the Nishnabotany at Harlan and Atlantic, the Little Sioux at Cherokee, etc.

PRESENT SLOPES OF THE MISSOURI AND BIG SIOUX.

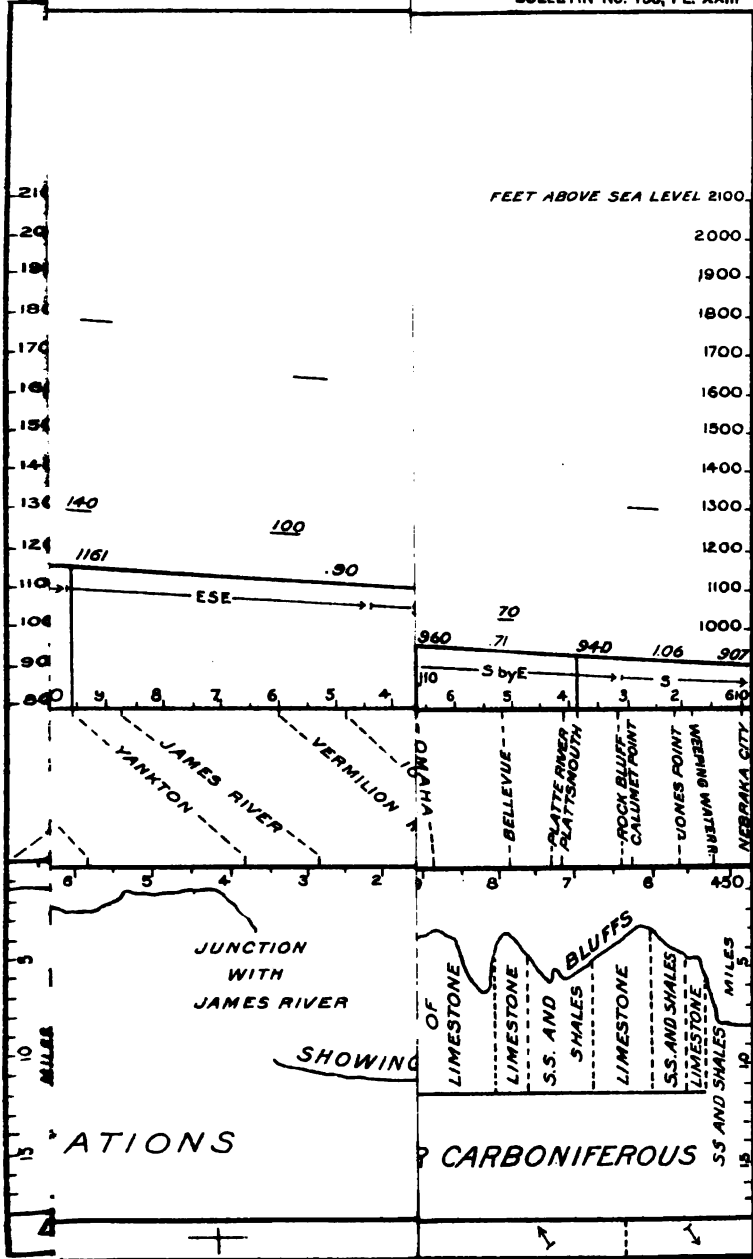
From railroad levels and the Government survey of the Missouri we obtain the following:

<i>Low-water slopes of the Missouri and the Big Sioux.</i>		
Missouri:		Feet per mile.
Pierre to Chamberlain		0.97
Chamberlain to Niobrara		.93
Niobrara to Yankton		1.02
Yankton to Sioux City		.90
Sioux City to Blair		.87
Blair to Omaha		.81
Omaha to Plattsmouth		.71
Plattsmouth to Nebraska City		1.06
Big Sioux:		
Flandreau to Dell Rapids		2.26
Dell Rapids to Sioux Falls		3.46
Brandon to Hawarden		2.25
Hawarden to Sioux City		1.00

AGE OF THE TERRACES.

If we accept the prevalent view that the outer moraine marks the maximum extent of the ice in the second Glacial epoch and that the formations outside belong to an earlier epoch, it readily follows that what we have grouped under the head of "lower bouldery terraces" belong to the later time. Their fresh contour and their relation to the loess and extra morainic drift all harmonize with this view. Looking further, the twofold grouping of these terraces would correspond well to the outer and second moraines. The lower terraces would as easily be referred to the times of the third, fourth, and later moraines. Their silty character would result from their remoteness from the glaciers, much as is found to be true of the higher terraces below Sioux City, when the river had left the vicinity of the ice during its earlier and greater extension.

The higher bouldery terraces, according to the scheme adopted, would be referred to a time preceding the loess, probably the first subepoch of the earlier epoch.



HEOUGH OF THE MIS

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More careful study of the terraces, especially after artificial exposures have been multiplied by the settlement of the country, promises to be one of the most interesting and instructive fields in Pleistocene geology. The above is only a beginning of what may be done.

DIAGRAM OF THE TROUGH OF THE MISSOURI.

We have subjoined a diagram (Pl. XXIII) showing graphically the slope, width, depth, terraces, etc., of the trough of the Missouri River from Pierre to Nebraska City. Its data are derived from the reports of the Missouri River Commission, railroad levels, and personal observations. Two things of interest are specially notable: One, the difference in width above Yankton as compared with the portion below that point; the other, the close correspondence between the width of the trough and the softness of the geological strata corraded. The remarkable width of the trough from Sioux City to Blair is probably largely due to the assistance of escaping artesian waters from the Dakota formation.

A similar diagram, somewhat abridged, showing similar facts for the Missouri below Nebraska City, may be found in Report of Missouri Geological Survey, Vol. X, 1896, p. 188.

WESTWARD ELEVATION OF THE REGION.

We have referred several times to a possible recent westward elevation of the region under consideration. We will now consider facts which bear upon its amount, extent, and age. These will be of value, even if not found decisive.

Along the line between Mitchell and Chamberlain the slope of the surface, where it is unaffected by local erosion, descends toward the east about 10 feet to the mile. This we may refer partly to the action of the ice sheet; but comparing it with the opposite side of the valley there is left a considerable amount to be explained by some other cause than the erosion of the ice. Farther south we find the same slope prevailing between Pratt Creek and the James River. We even find that the plain between the Big Sioux and the Vermilion east of Parker is 50 to 75 feet lower than the plain between the West Vermilion and Wolf Creek west of that place. The determination of the prevalent slope farther south in Dakota is rendered difficult by the occurrence of interlobular portions of the moraine. If we refer to the table of elevations along the moraine given in our first chapter we find them harmonizing with the idea of a considerable westward elevation.

Passing now into Nebraska we find, it will be remembered, the surface composed mostly of loess, which in its westward portion presents a clearly defined and quite recognizable plateau. Upon this we may take a number of elevations which will indicate very satisfactorily the general slope of the country. Farther east, with a little care, the original or prevalent level of the loess may be determined from the few

- isolated remnants which appear to be the original surface. The following table presents the results of such determinations along lines extending east and west. The figures may be more relied upon in the western portion of the field because more closely connected with railroad elevations. In the eastern portion, though largely barometric, it is believed that they have need of only slight correction.

Slope in eastern Nebraska.

Locality.	Distance.	
	Miles.	Feet.
Kimball to Mitchell	48	10
Northside to Emerson, Nebraska.....	30	6.6
Oakdale to Wisner (Elkhorn Valley).....	57	5.9
Humphreys to Blair	70	5.5
Platte Center to Mapleville.....	40	6.3
Mapleville to Blair	30	2.7
Columbus to Fremont (Platte Valley).....	47	5.5
Aurora to Utica	36	5.9
Hastings to Dorchester	68	6.5
Patterson to Sheldon, Iowa	14	1.5
Akron to Marcus, Iowa	33	1.6
South of Hillsdale to Creston.....	70	0

From this we learn: (1) That the James Valley and the Missouri below their junction mark approximately the axis west of which the western elevation is much more marked, averaging about 6 feet per mile. (2) That the slope east of that line is very slight, if anything. It amounts to about 1 foot per mile in northern Iowa, and may possibly be found to be less, for our observations are quite limited. Another reason for doubt lies in the fact that the elevation of the eastern edge of the loess has not been definitely determined, but it can not vary greatly from the figures given. (3) That the slope diminishes rapidly as it approaches the Missouri in eastern Nebraska, as is indicated by the slope between Mapleville and Blair.

A general view of the change of slope indicates that its axis follows approximately the boundary between the Cretaceous rocks and the older rocks. The Archean quartzites of Dakota seem to have been least affected. This axis, which is the eastern limit of the steeper westward acclivity north of our field, continues apparently up the James River through Brown County and then curving eastward around the head of Coteau des Prairies, extends into the valley of the Red River.

Date.—1. The relations of the drift to the volcanic ash stratum in eastern Nebraska and to the lacustrine beds in Mills County, Iowa, to say nothing of less definite beds pointing in the same direction, indi-

cate that during the Pliocene and on into the Glacial epoch the western elevation had not begun to affect materially the slope of the region under consideration. Farther west it may have considerably advanced before the advent of the ice.

2. The position of the ice sheet during the occupation of the principal moraine indicates little, if any, relative elevation toward the west. The westward pushing of the ice south of the Wessington Hills is difficult to explain if the slope of the land was as great as at present. The existence of the glacial lake around the Bijou Hills and above is more easily understood if the land was at a lower level than at present. Nevertheless, it is not fatal to the hypothesis to suppose the relative elevation to have been as great then as now.

3. The deposition of the loess, which we have conceived to be a fluvio-lacustrine formation, favors also a gentler slope than the present. The force of this argument would be somewhat weakened if it could be satisfactorily shown that the deposition of similarly fine material is consistent with considerable velocity in the depositing waters. We might then perhaps conceive the western portion of the loess to consist of the gigantic "alluvial fans" of the Niobrara, Elkhorn, and Platte, formed largely under subaerial conditions. Moreover, with an overloading of silt this would be more conceivable.

4. The deflection of the ice toward the east during the formation of the second moraine, together with the change of drainage about White Lake and Lake Andes, though perhaps not demanding, strongly favors the conclusion that the elevation had at that time become perceptible.

5. It will be noticed that the relation of the high terrace of the Platte River to the higher land in the vicinity of Fremont, Nebraska, suggests that the desertion of the old channel across Saunders County may have been due to its cutting through the divide which formerly separated the Platte from the Elkhorn, and that this was subsequent to the formation of the terrace. If the terrace was, as we have supposed, contemporaneous with the outer moraine, and the cutting through at Fremont was the result of an increased slope of the river, it follows that the elevation was still in progress after the occupation of that moraine, and may have continued indefinitely.

6. Another feature of the terraces points to the same general conclusion. Along the Missouri River between Monona County, Iowa, and the southern line of the State, there are no high terraces of importance on the east side of its present valley. There are a few points where the terraces along its eastern tributaries appear, but they do not project beyond the trend of the present bluffs. Along its western side, on the contrary, as we have already noticed, there are extensive terraces 60 to 100 feet high, found between Tekamah and Calhoun, between Florence and Omaha, and between Bellevue and the mouth of the Papillion, so also near the mouth of the Weeping Water. If no tilting had occurred, the converse should be true, for the rule that the streams in

the northern hemisphere erode more rapidly the right side of the valleys has few exceptions.

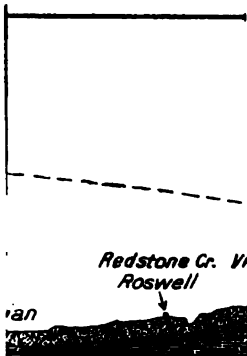
Whether the upward movement continues to the present is uncertain. The slight slope of the Missouri from Chamberlain to Sioux City would seem to favor the idea that such is not the case, and yet the corrosion of the stream may possibly keep pace with the slow elevation which may still continue. That river is so laden with sand that the deepening of its real bed may be so masked as to be undiscoverable. Considerable light upon this subject in general may be derived from the general sections. Pls. XXIV and XXV.

NORTHWARD ELEVATION OF THE REGION.

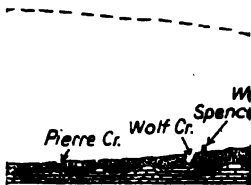
In our tables of elevation marking the general level of the loess there appeared a marked slope to the south. This is brought out very distinctly in the list of elevations, which is arranged for the most part along north-south lines. While this feature is most clearly indicated in Nebraska, it appears also in less degree in western Iowa, also in the valley of the Big Sioux above Sioux Falls, and in the southern portion of the region within the principal moraine. The following table will illustrate and impress these points:

Slope in western Iowa.

Locality.	Distance.		Slope per mile.
	Miles.	Feet.	
Plainview to Humphreys, Nebraska	54	2.5	
Osceola to Fairmount, Nebraska	42	.8	
Plainview to Fairmount, Nebraska	125	1.3	
Southwest of Coleridge to Northside, Nebraska	25	.4	
David City to Dorchester, Nebraska	42	1.2	
Coleridge to Dorchester, Nebraska	127	2.6	
Blair to Louisville, Nebraska	35	3.5	
Louisville to Turlington, Nebraska	21	1.2	
Blair to Turlington, Nebraska	56	2.6	
Sibley to Marcus, Iowa	40	1.3	
Marcus to Hillsdale, Iowa	125	1.3	
Sioux City to California Junction (Missouri Valley)	70	1.4	
Missouri Valley to East Nebraska City	62	1.5	
Wentworth to Taopi, South Dakota	13	3	
Taopi to Hartford, South Dakota	13	5	
Wentworth to Hartford, South Dakota	26	4	
Airlie, Minnesota, to Larchwood, Iowa	38	4.4	
Lenox to Vermilion, South Dakota	37	3.5	
Plankinton to Grandview, South Dakota	23	— 1.3	



D" TO PIPEST



ND" NORTH C



RTY-NINTH PA



EAST AND WEI

The localities in the above table stand for the upland in their vicinity. Further information is afforded by the general sections, Pl. XXV.

From a study of this table we come to the following general conclusions: The region outside of the principal moraine has uniformly a general slope toward the south. In the loess region this averages on the long slopes from 1.3 to 2.6 feet per mile. In the Coteau des Prairies region it is from 4 to 5 feet per mile. Between the outer and the second moraines there exists on the east a slope of 3.5 feet to the mile, but west of the James there is a rise southward of from 1 to 1.5 feet per mile from the line of the Chicago, Milwaukee and St. Paul Railway. This irregularity may be connected with a slight increase of elevation of the loess summits from the vicinity of the Missouri south to the southern borders of Knox and Cedar counties, and be made to argue for the recent anticline, with its axis running east and west, near the Niobrara. Gen. G. K. Warren arrived at a similar conclusion from independent data noted farther west.¹ This hypothesis may help to relieve two other difficulties of some weight—the absence of the loess along the Missouri north of the Niobrara at levels below its summit in Knox County, Nebraska, and the difference in elevation of the lower bowldery terrace at Running Water and Vermilion, Dakota.

An examination of the James River Valley brings out the remarkable fact that within the second moraine the general level of the valley is exactly horizontal in a north-south direction. From the vicinity of Mitchell to Columbia and beyond, for more than 140 miles, the variation in altitude according to railroad elevations (notice especially those of the Chicago, Milwaukee and St. Paul Railway) is scarcely 10 feet. Letcher, Diana, Cavour, Redfield, Ashton, Aberdeen, Groton, and Columbia are all above the plain which we have named for convenience Lake Dakota.

Date.—From the steep slope of the drift plain of the Coteau des Prairies of the upper Big Sioux, we infer the existence of a northern elevation before the loess epoch. Quite probably, however, that greater slope is to be referred to a considerable elevation since that time. Being between the Dakota and Minnesota lobes, it would be naturally depressed more than lower latitudes, and when the ice was removed its resilience would be correspondingly energetic.

The generally distinct and continuous slope of the region to the south, wherever the loess has been deposited, is no more than a fluvio-lacustrine theory of the loess would explain without perceptible crustal movement. This northward slope for the most part was quite regular. We have noted the most apparent exception, concerning which we need add no more at present.

From the perfect horizontality of the general surface within the second moraine, which, although of lacustrine origin, seems to be continuous with the surrounding till, we conclude that the elevation must

¹ Preliminary Report of Explorations in Nebraska and Dakota, 1855-57, pp. 23, 24.

have ceased for southern Dakota by the time the ice had receded to the third moraine; and we have found no evidence that this elevation has continued in any other portion of our field.

AGE OF THE TROUGH OF THE MISSOURI.

In regions north of the field covered by this paper evidence is especially strong that the courses of such streams as the Cheyenne and Grand rivers were formerly eastward to the valley now occupied by the James River. This is derived mainly from the movements of the ice sheet, the traces of old divides, and the narrow character of the trough of the Missouri through this region. For fuller treatment of this topic, see a paper by the writer in the Proceedings of the American Association for the Advancement of Science for 1884.

There is evidence, also, in the region under consideration which indicates that the channel of the Missouri above Niobrara is of recent origin. The White River has a channel rivaling or even surpassing the Missouri in breadth if we consider its broad ancient valley 300 feet above the present one. There is no valley through the Bijou Range of buttes which corresponds to it in size. The Bijou Range itself seems to be an old watershed or remnant of Tertiary rocks which extends between the basins of the White and Niobrara rivers. What the ancient course of the White River was there is not yet evidence of much importance to show, but, remembering the higher level at which it formerly flowed, it may be suggested that a portion of its course remains in the Red Lake channel. Nor is it very difficult to imagine that it once ran along the upper course of American Creek past White Lake.

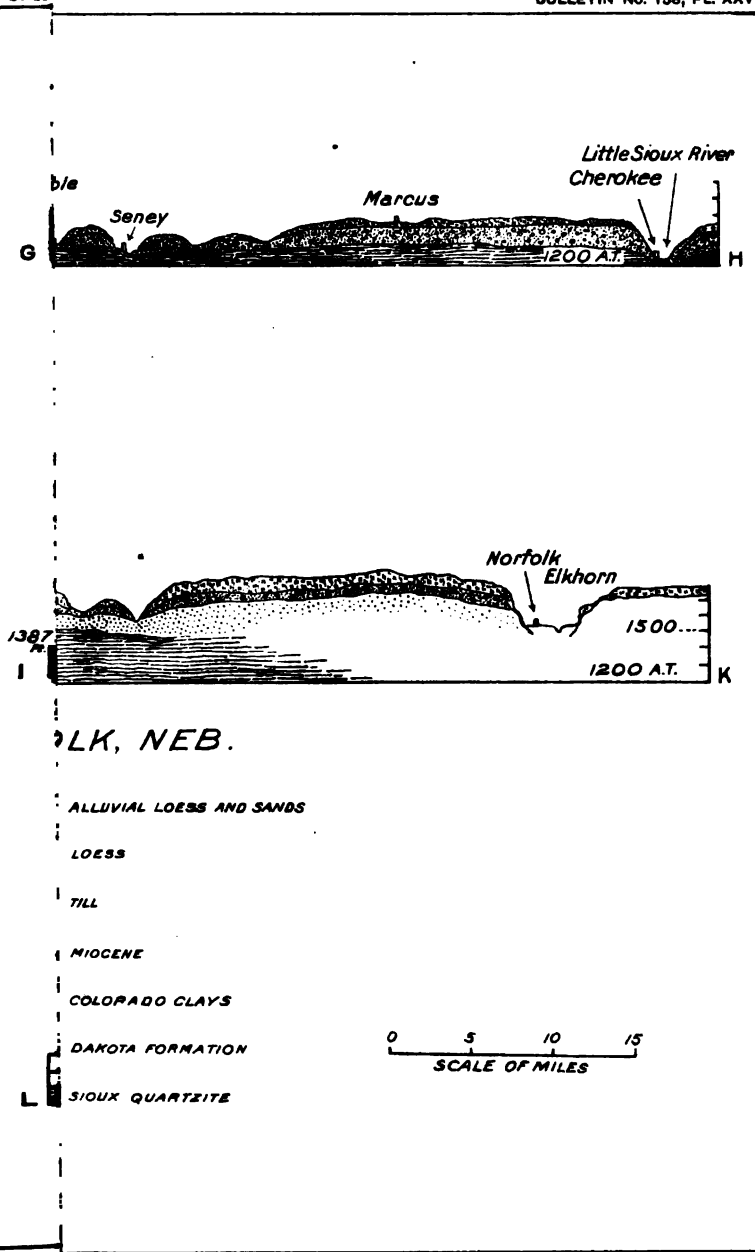
It now remains to consider the age of the Missouri below that point, more particularly that portion bordering the State of Nebraska. Two questions present themselves: 1. Was it pre-Glacial, so far as its location, or was it post-Glacial in origin? 2. If post-Glacial, did it reach its deepest excavation before the loess epoch or in more recent times? If we should find reason for believing it of pre-Glacial origin, the exact date of its location and excavation are not particularly connected with our subject.

IS THE TROUGH OF THE MISSOURI OF PRE-GLACIAL ORIGIN?

We proceed to take up the first of these questions. In favor of the pre-Glacial origin of the trough the following points may be urged:

1. Striæ, supposed to be of Glacial origin, have been found down to the level of the water at Omaha, and very nearly down to that level in southwestern Mills County, Iowa. Not unlikely more careful examination would disclose such striæ at other points.

2. The bed rock lies at a depth of from 50 to 110 feet, or even 125 feet at Omaha, below the present low-water mark; and this leads us to pre-



sent in more careful detail the results of examination at five different points, viz: Sioux City, Blair, Omaha, Plattsmouth, and Nebraska City. In the first three cases sections have been kindly furnished the Survey by the engineers of the railroads which cross at these several points. A few notes from engineer Parkhurst, of the Plattsmouth bridge, were received soon after its building. The Nebraska City section has been constructed from notes, taken by the writer in 1880, of an examination carried on by the Corps of United States Engineers, who, to throw light on the history and working of the Missouri, ran a line of borings nearly across the valley at that place. The main facts at these different points may be stated as follows (for a full expression of them we refer to the subjoined cross sections in Pls. XXVI and XXVII):

At Sioux City the river hugs the eastern bank. The rock, judging from that exposed in the bank, is wholly of Dakota sandstone and shales. The river at this point is about 900 feet in breadth and from 5 to 15 feet in depth. The rock lies underneath the present channel of the river on an average from 35 to 80 feet. It lies approximately parallel to the bottom of the water, but near the western bank slopes downward toward the west, and its depth beyond that point has not been determined. These remarks apply particularly to the section near Prospect Hill. The new one, upon which the Pacific Short Line is built, does not differ materially from it. Along the line of the lower bridge, that of the Sioux City and Pacific Railroad, quite different conditions were found. The three deeper borings in the vicinity of the channel, though extending 120 feet below the low-water mark, are reported not to have struck any bed rock. The section is illustrated in Pl. XXVI. When we learn that the Dakota formation is composed mainly of sand, with thin layers of clay, it seems not improbable that its strata may have been mistaken for the loose deposit of the river. In favor of that fact attention is called to the representation of white clay, blue clay, and sand upon the east bank, which would correspond in character with strata of the Dakota. Moreover, upon the west bank, at a depth of 70 feet, is a stratum of clay with its upper surface concave, as though worn by a stream, which also suggests a stratum of the Dakota. Taking the borings as given in the report of the Missouri River Commission for 1890, however, it would appear that river deposits extend to a depth of 120 feet, and how much more has not been determined.

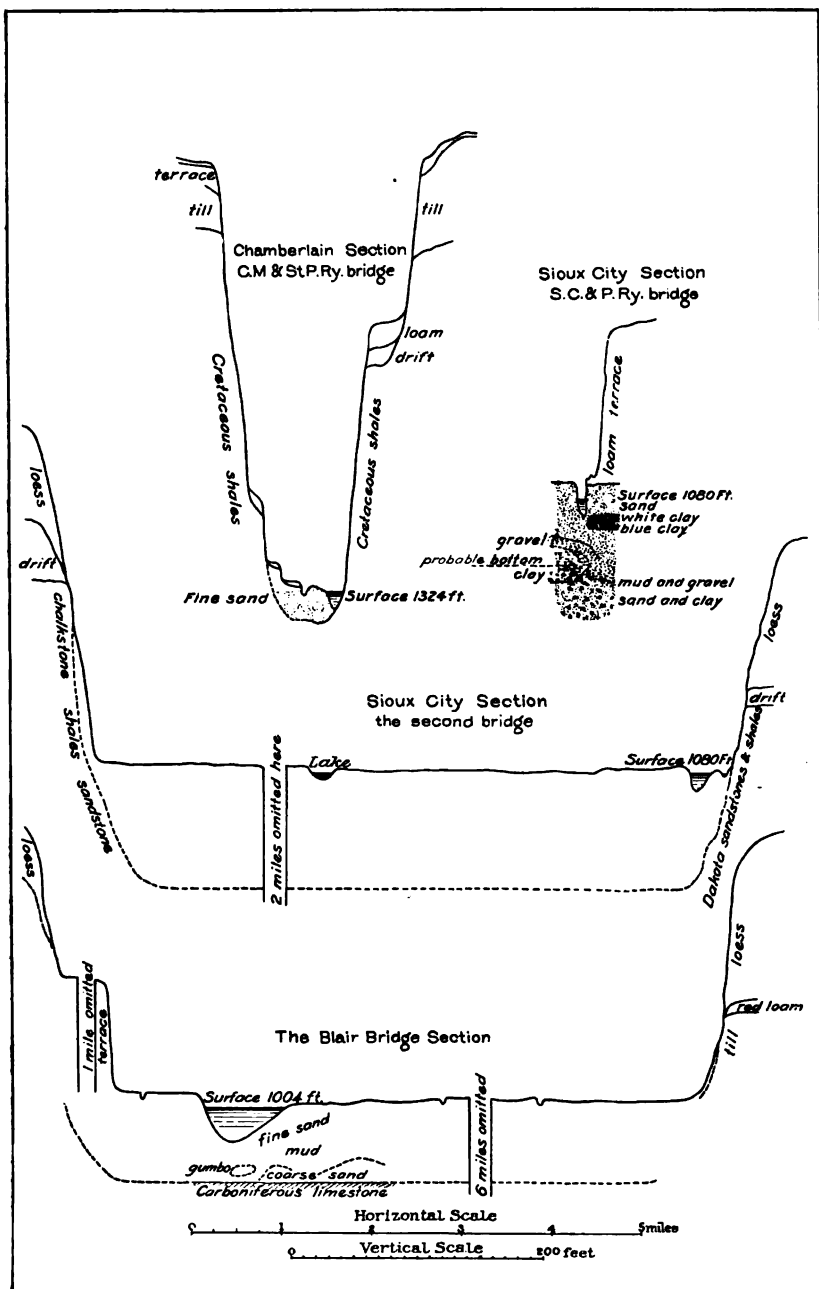
At Blair the river occupies a more central portion of a valley 11 to 12 miles in width. It is three-quarters of a mile east of the high terrace at Blair. The bed rock in the vicinity of the present channel, where the bridge of the Sioux City and Pacific Railroad crosses it, is from 47 to 50 feet below low-water mark. Its surface is quite level in an east-west direction, but seems to dip, or at least to end, abruptly to the north, for a boring 1 mile north of the bridge did not reach rock at a depth of 140 feet. Borings for a mile longitudinally near the bridge, however, indicate a slight decline of surface toward the south.

At the railroad bridge at Omaha the river lies close to the western bank, and, as has been stated before, the rock near by rises above the level of the stream. Underneath the present channel, which at this point is ordinarily about 1,000 feet in width and 2 to 15 feet in depth, bed rock lies from 30 to 75 feet below low-water mark. These remarks apply to a section of the Union Pacific Railroad bridge. The section given in our illustration (Pl. XXVII) is that determined by a set of borings crossing the river about half a mile north of the Omaha and Council Bluffs wagon bridge. In this there appears a shelf in the rock bottom on the Omaha side about 20 feet below the surface, or 15 feet below low water. A little east of the river and for three-quarters of a mile farther in that direction the rock lies at a depth of about 80 feet, and three borings east of that failed to strike bed rock, though penetrated to a depth of 90 feet. Moreover, the character of the deposits seems to be that of the river, or possibly, in one case, boulder clay. It is labeled clay and gravel.

At Plattsmouth a much less complete section has been obtained, but the river is close to the western side of the valley and the rock lies from 32 to 54 feet below low-water mark. Moreover, more recent borings have developed the fact that the bottom is quite uneven, and that in some places bed rock lies considerably lower. About a mile and a half farther north borings were carried to a depth of over 85 feet without striking rock.

At Nebraska City the river also lies next the western side of a valley 8 miles in width. The river is about 1,000 feet in breadth, and in places 30 to 40 feet in depth. By the borings before referred to, which were carried on under the directions of Mr. L. E. Cooley, assistant United States engineer, for more than 4 miles, at distances of from 2,500 to 3,000 feet apart, the rock was found to lie at a depth of from 60 to 102 feet below low-water mark. The deepest point found was at the easternmost boring where, according to his statement, "boulder clay" was struck, suggesting the idea that it may have been the western side of an old channel partially filled with boulder clay. The average depth of the rock, which on the whole is quite even, may be placed at about 75 feet below low-water mark.

From the Report of the Missouri River Commission for 1890 we learn that north of the bridge about 2 miles borings were carried to a depth of about 170 feet at several points before striking bed rock, and the inference drawn by the engineer was that he had discovered a pre-Glacial channel. He reports that the "principal bed below the general level of the north and south valley of the Missouri is a very tenacious, hard, drab-colored clay, mixed with angular fragments of stone, generally of lime," though he reports one of red quartzite, but it is not from this deep channel. He does not doubt that it is till. Assuming that this deep hole is connected with the easternmost boring shown in our figure, he makes the channel run S. 80° E., and suggests that it



SECTIONS ACROSS MISSOURI RIVER AT CHAMBERLAIN, SIOUX CITY, AND BLAIR.

may be a portion of an old valley of the Platte. It is difficult to harmonize it with the present Missouri. On the whole, it seems more rational to suppose that the deposit in question is a Carboniferous stratum, and that he has been misled by the interruption or removal of a thin layer of limestone which has, near by, formed the bottom. However, the case should be remembered and further light be sought on the subject.

Now, it appears improbable that the present stream should be still excavating the rock bounding its trough; its depth is too great, it would seem. And yet, at what time since the Glacial epoch is it likely to have reached the bed rock under its channel? On generally received principles we should be inclined, from the depth of the rock, to argue for the pre-Glacial excavation of the trough. Whether this is strongly sustained we shall see presently.

3. The occurrence of till quite low down. At Florence it is found 50 feet thick and more, extending below low-water mark. North of Council Bluffs, near Plattsmouth, and in Mills County, Iowa, typical till is found down to within 30 feet of the level of the river.

In favor of the post-Glacial origin of the immediate valley of the Missouri, it may be argued as follows:

1. A comparison of the course of the Missouri with that of the Mississippi on opposite sides of the State of Iowa brings out the contrast that, while the latter presents rapids of considerable height, nothing of the kind is found along the Missouri. As these rapids have been distinctly traced to changes in the course of the Mississippi during the Glacial epoch, or the want of correspondence of its present channel with that of pre-Glacial times, the absence of rapids in the Missouri would argue in favor of no such divergence, and since we should as easily expect a similar divergence in one case as in the other, if both had pre-Glacial channels, we have some reason for believing that the Missouri had no pre-Glacial channel.

2. Deposits which are evidently of lacustrine and of pre-Glacial origin are found in such close proximity to the present valley as to argue against the idea of a river occupying the trough previous to the deposit of the till. We refer particularly to the section north of Pacific Junction, which has been described on a previous page. This, however, is not conclusive, for we may conceive of small lakes attending a river.

3. Wherever the deposits have been examined in the present trough of the Missouri they have displayed only sand and clay, with no trace of till except in one solitary case, which has been mentioned in the Nebraska City section Pl. XXVII. At Blair and Omaha a few scattered bowlders are found next the rock, but they have evidently been rolled along by the action of the water. At Nebraska City and Omaha clay balls, evidently formed by the caving of clay banks and the rolling of the fragments by the current, occur frequently down to the rock. If the trough were of pre-Glacial age it should be found filled more or less

with bowlder clay. Even if it has been more deeply excavated since the ice age, till should be found occupying a considerable part of the trough.

4. The bed rock, wherever it has been exposed, as at Blair and at Omaha, has shown a uniformly waterworn appearance, with no traces of planation or striæ. Though bowlders have been found upon the surface of the rock to the depth of a foot or so, there is no evidence of their corradng the rock as if moved by ice.

We may sum up the evidence from the sections with this result: The depth of bed rock differs much in the different sections, even where the localities seem quite uniform. It will be remembered that a boring 1 mile north of Blair bridge is said to have gone 140 feet without striking bed rock. When we consider the greatly different kinds of material which the river has excavated it seems likely that the deepness of the channels is the result of softness of the material rather than of great age or the position of an ancient base level. It seems probable that there would be variations in the depth of the trough of the river similar to those in its width, and the causes for each are probably similar. Hence we conclude that the preponderance of evidence is in favor of a recent excavation of the lower portions of the channel. At the same time it should be remembered that we have no complete sections across the trough and that there is a possibility that an older and deeper channel of pre-Glacial age may yet be found.

THE TROUGH OF THE MISSOURI STILL DEEPENING.

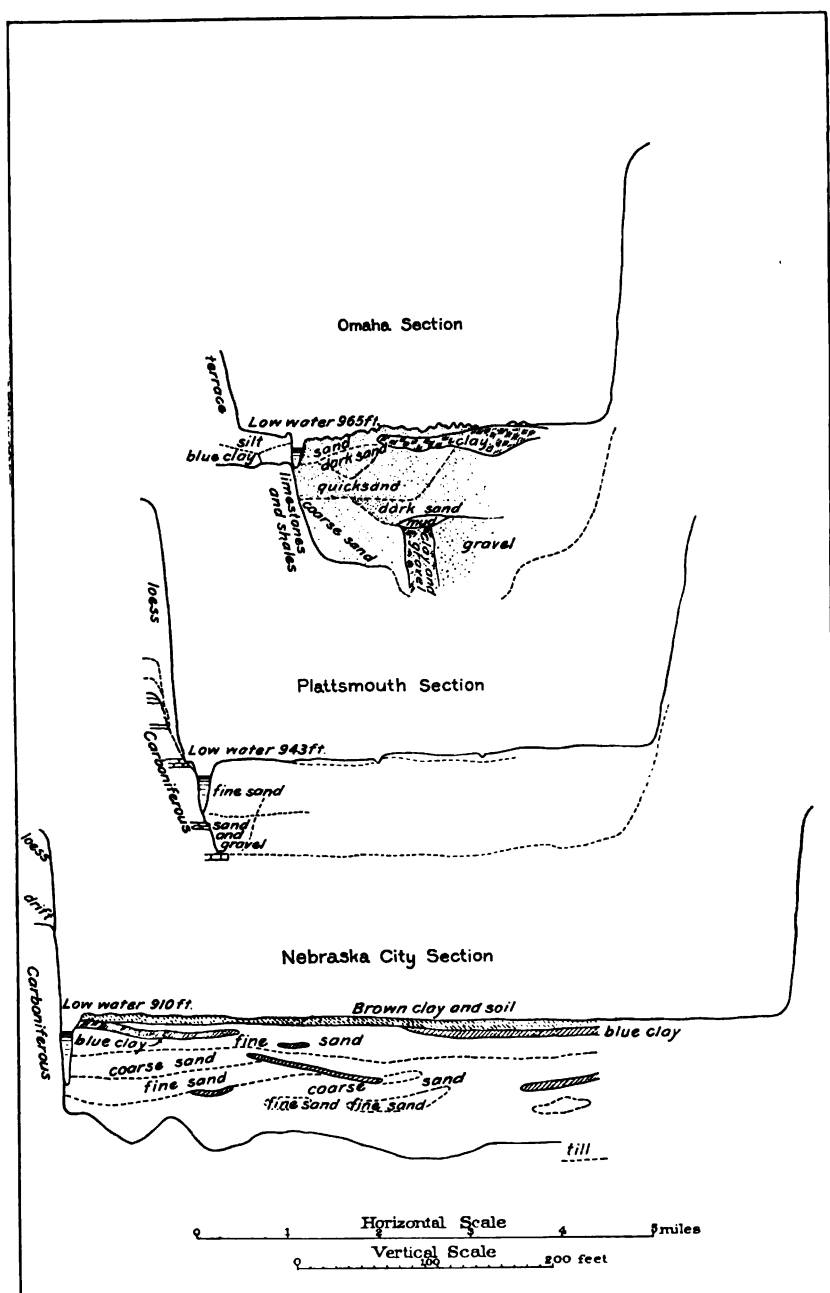
In support of the view, which may strike some as novel, that the river may cut down to the bed rock at the present time during freshets, we have the united testimony of two or three experienced observers. Mr. L. E. Cooley, in his report on the improvement of the Missouri River at Nebraska City during the year 1879,¹ makes the following statement:

The ordinary limit of scour is not the limit when the bank is held, provided the ordinary scour does not extend to permanent strata. The causes which induce heavy cutting will induce heavy scour, provided that cutting is stopped, which will extend to permanent strata if the causes continue sufficiently long. * * *

In many of the borings which have been made here, indurated clay balls, with vegetable matter, covered with a coating of sand, along with a motley collection of gravel stones, are found within a short distance of permanent strata. A precisely similar collection containing gumbo balls in a soft state was dredged from 60 feet depth at the works. These balls are from cutting banks, and the proof is conclusive that since the river has been running in silt banks, as at present, scour has occasionally, at least, reached permanent strata at 70 to 90 feet depth.

Mr. E. Gerber, assistant engineer of the Fremont, Elkhorn and Missouri Valley Railroad, who has had direct oversight of the Blair bridge, states without qualification that the river at that point cuts down to bed rock twice a year, and he further expresses the opinion that "At many places, especially in sharp bends, where no artificial contraction of the channel takes place, and where there is no greater width than

¹ Report of U. S. Engineers for 1879-80, Part II, pp. 1066, 1071.



SECTIONS ACROSS MISSOURI RIVER AT OMAHA, PLATTSMOUTH, AND NEBRASKA CITY.

at our bridge, the river scours the bed rock at high water if the rock is not too low." A demonstration of this fact is shown in fig. 31 from soundings taken at the Blair bridge in 1883.

Mr. George A. Lederle, local engineer of the Omaha bridge, expresses a similar opinion, though no definite observations have been made at that point to establish it.

If it be urged that the excavation of so great a valley as is found above Blair and near Nebraska City since the Glacial period is inconceivable, it may be replied that much may be explained by the nature of the formations through which the river has corraded its course.

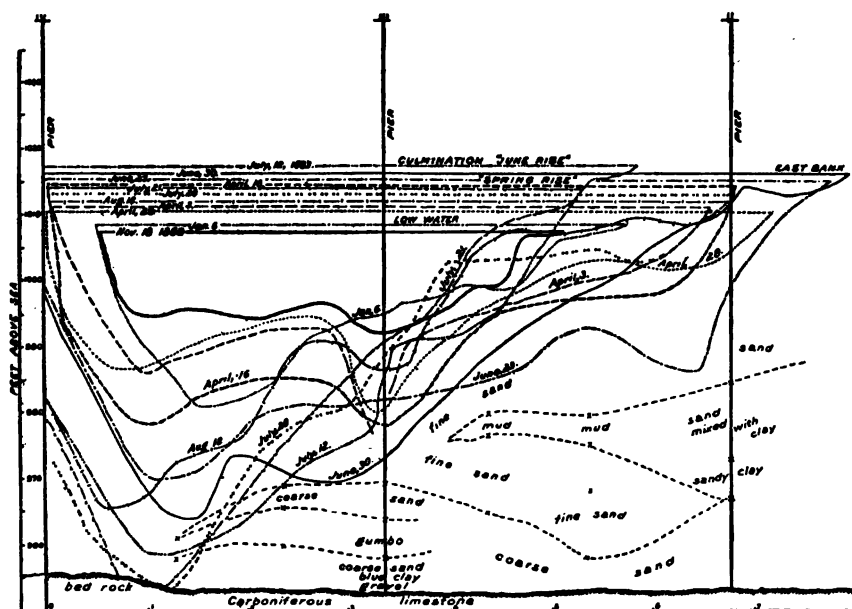


FIG. 31.—Record of soundings at Blair bridge, 1883.

Above Blair the Carboniferous limestone does not appear, and doubtless dips far below the bottom of the river. The great width of the valley above that point has been excavated, therefore, in the loose deposits of the Cretaceous and Tertiary, while its deepening was prevented by the limestone ledge near Blair and De Soto. Even the Carboniferous deposits, though at points largely abounding in limestone, are perhaps one-half clay and very friable sandstone and shale. Moreover, the limestone ledges are rarely more than 10 feet in thickness, and the thickest easily separate into blocks less than 3 feet in diameter. Cliffs of alternating rock and clay may be quite as easily degraded as those of clay alone.

The inequalities of the depth of the bed rock seem to correspond with the character of the strata. For instance, at Blair the shallowness of the trough seems to be referable to a thick stratum which appears above the river at Omaha; the shallowness at Plattsmouth, to

a thick limestone stratum which appears a little above the river at Rock Bluff. The rock thus far dips gently toward the north. The greater depth at Omaha may be due to the series of clay layers which intervene between the two, together with the effect of the plunging of the current over the limestone stratum as it was worn from the south toward the north. The great depth at Nebraska City may be similarly referred to the rapidity of the stream after passing the limestone stratum at Rock Bluff. Quite possibly, also, this has been increased by a fold which crosses the river at Jones Point, near the mouth of the Weeping Water. The strata dip considerably to the south, perhaps 100 feet in the distance of a mile. This brings the series of clays which are exposed in the vicinity of Nebraska City down into the river and accounts for the deeper excavation at that point.

The *modus operandi* of the excavation of the trough seems to be in this wise: While the stream has rapid velocity it preserves much of its straight, narrow, deep channel, which characterizes its upper portion, but when such a channel has attained a uniform slope it begins to form bends which begin the widening of its valley. During this stage the deepest places are in the sharp bends, and only at such points has the river rock bottom. If it is heavily burdened with sand and silt, as in the case of the Missouri, between such bends, according to the testimony of engineers as well as the common experience of river captains, the river is very shallow, as the current here is slackened and sand accumulates, especially during high water.

As the river meanders back and forth and the bends continually work down stream, the whole breadth of the valley becomes scoured out to the depth of the sharpest bends. In this way we may reconcile its present partially filled condition with its recent excavation. The work of broadening the trough does not begin at all points at the same time. Where the strata are soft and friable the stream reaches its base-level of erosion, and expends its energy in widening its valley, while at points where harder strata occur it is spending all its energy in cutting out its bottom.¹ Thus we may explain, in part at least, the remarkable widening of the trough of the Missouri between Yankton and Blair, and in less degree between Council Bluffs and Rock Bluff, and again between Jones Point and Peru.

We conclude, therefore, that though the trough may possibly have been located before the Ice age, its deeper portions must have been excavated after the deposition of the surrounding till. Moreover, this excavation may have begun soon after the Iowan or even the Kansan stage of the Glacial period.²

If it should be asked how we reconcile the arguments in favor of its pre-Glacial origin with the conclusion at which we have arrived, we should simply ascribe the striæ preferably to the action of river ice, though they may have been caused by land ice of an older epoch, and

¹ Cf. Powell's *Exploration of the Colorado River*, p. 202 et seq.

² Cf. Todd, *New lights on the drifts*: *Proc. Iowa Acad. Sci.*, 1896.

the deposition of till at altitudes near the river where it is not the result of landslides to depressions in the surface on which the till was deposited, for the general surface of the Carboniferous strata seems to have been far from even. The deep deposits of sand and gravel in the vicinity of Council Bluffs and Omaha we should ascribe to similar cause. It would seem that when the Missouri began its course during or after the drift period, and in crossing some of these deep holes large quantities of this material collected in them.

The very rough surface of the Carboniferous rocks is graphically described by Dr. F. V. Hayden in his Final Report on Nebraska, p. 25. Speaking of eastern Nebraska, he says: "If we can imagine the superficial material entirely removed from the country, the surface, as it seems to me, would be rugged in the extreme. * * * The massive piles of limestone would stand around here and there scattered over the surface like gigantic ruins." This quotation, while expressing a truth, may be misunderstood. If we should remove the pre-Glacial clays and sand beds the buttes of Carboniferous limestone would probably rise less than 200 feet above the intervening valleys.

If this conclusion be correct, there may not have been very great erosion of the older rocks since the Ice age.

WAS THE TROUGH EXCAVATED PREVIOUS TO THE LOESS EPOCH?

This depends largely upon the theory one may hold concerning the origin of the loess. If it is looked upon as eolian, the two may have been developing simultaneously. In that case the conception would be that the Missouri began its course after the Kansan epoch, and that the material of the loess must have been derived from its bars and banks during its lower stages and spread over the uneven surface adjacent. But if we look upon it as of a lacustrine or a fluvio-lacustrine origin, it would seem necessary to conceive the trough of the Missouri to have been subsequent. If we favor the latter views, the base-level of erosion and deposition must have been approximately coincident with the present upland level of the loess region. We may have some fragments of the original surface still extant in the "flats" which we have already mentioned as occurring in western Iowa, Nebraska, and Missouri. Accordingly, the most of the upland loess was deposited no later than the Iowan epoch. If it seems incredible that this trough, which really is of vast extent, has been excavated since that time, we may find it more credible by considering the following points:

1. The present trough may have been largely excavated from Pleistocene deposits. We have already alluded to the very uneven surface of the older rocks. If the drift were resting upon deep sand beds, as has been found in northern Nebraska, this would assist largely in the removal of the material.

2. The Missouri during the Wisconsin epoch was the main channel for carrying off the water from the whole western edge of the great ice sheet. Estimates will be found more fully given in the Report of the

Missouri Geological Survey, Vol. X, p. 202. According to these, the probable average size of the stream was about ten times greater than at present. This would add greatly to its eroding power.

3. The loess has a peculiar property for creeping and rearranging itself at lower levels. This subject will be found more fully treated in the Proceedings of the Iowa Academy of Sciences for 1897. We simply call attention here to the following facts: The loess upon steep slopes frequently shows a step-like surface. Most generally it attracts little attention, and has been referred by some to the checking by vegetation along steep hillsides or to the tramping of grazing animals. Even in this moderate degree deep excavations will show that these steps are caused by a series of slight faults running transverse to the direction of the slopes. They may be compared to crevasses of glaciers. It appears that this phenomenon occurs when moisture has accumulated in the base of the formation and dissolved the cementing material of the loess and rendered it plastic, or the moisture may be in the underlying clay or sand, rendering it similarly plastic. Occasionally this phenomenon becomes so marked that the crevasses or faults have a throw of several inches. During rain or the spring thaws these cracks are filled and recemented. Similar results are also accomplished by hillside wash, which frequently becomes very marked upon steep slopes. After prolonged rains the formation becomes saturated and is very easily washed away and rearranged. Because of its straticulate structure and homogeneous color and composition it is very difficult for anyone to distinguish the newly arranged material from the original deposits. In this way we may find a rational explanation of the recent origin of the troughs of the Missouri and its tributary streams, and also in considerable degree of the uneven surface and great vertical range of both the loess and the drift.

ELEVATIONS.

Elevation above sea level of stations on Fremont, Elkhorn and Missouri Valley Railroad west of Norfolk Junction.

[Furnished by the kindness of E. Gerber, assistant engineer.]

Main line:	Feet.	Main line—Continued:	Feet.
Battle Creek	1,606	Ainsworth	2,538
Burnett.....	1,685	Johnstown	2,618
Oakdale	1,726	Wood Lake	2,704
Neligh	1,761	Arabia	2,735
Clearwater.....	1,808	Thatcher.....	2,669
Ewing	1,875	Valentine	2,598
Inman	1,946	Creighton Branch:	
O'Neill.....	1,992	Norfolk (town) ¹	1,542
Emmet.....	2,039	Hadar	1,574
Atkinson.....	2,125	Pierce	1,599
Stuart	2,171	Morehouse	1,657
Newport	2,249	Plainview.....	1,700
Bassett	2,340	Creighton	1,617
Long Pine	2,416		

¹ This is 1 mile from the junction, which is 1,532 feet.

Elevations on the Chicago, St. Paul, Minneapolis and Omaha Railway.

[Furnished by the kindness of C. W. Johnson, chief engineer.]

Locality.	Distance.	Altitude.
Main line:	<i>Miles.</i>	<i>Feet.</i>
Sioux City, crossing of Second and Howard streets .....	.....	1, 122. 2
Missouri River .....	.....	1, 102. 33
Covington	0	1, 124
Dakota City	5	1, 121
Coburn Junction	10	1, 124
Do	12	1, 125
Hubbard	14	1, 161
Grade over Pigeon Creek	20. 5	1, 356
Bottom of Pigeon Creek	20. 5	1, 307
Simons Siding (summit)	22	1, 436
Grade of Elk Creek	23. 5	1, 356
Bottom of Elk Creek	23. 5	1, 336
Do	23. 6	1, 352
Summit	26. 2	1, 494
Emerson Junction	27. 2	1, 450
Flourney	34. 5	1, 399
Pender	39	1, 347
Bancroft	48. 7	1, 316
Lyons	56. 3	1, 306
Oakland	65	1, 300. 3
Craig	70	1, 280
Summit	71. 5	1, 341
Tekamah	79	1, 075
Herman	86. 2	1, 050
Hiland	91. 2	1, 031
Blair	96. 2	1, 100
Mills	101. 5	1, 026
Calhoun	105. 2	1, 094
Summit	116	1, 232
Florence	120	1, 033
Omaha	126. 2	1, 065
Ponca Branch:		
Coburn Junction	0	1, 124
Jackson	3	1, 141
Grade at Elk Creek	4. 2	1, 156
Bottom of Elk Creek	4. 2	1, 140
Grade at Elk Creek	6	1, 174
Bottom of Elk Creek	6	1, 152
Summit	11	1, 279
Grade at Badger Creek	11. 5	1, 243
Bottom of Badger Creek	11. 5	1, 225
Ponca	16	1, 162

Elevations on the Chicago, St. Paul, Minneapolis and Omaha Railway—Continued.

Locality.	Distance.	Altitude.
Norfolk Branch:	Miles.	Feet.
Emerson	0	1,450
Summit	2.5	1,541
Wakefield.....	9.5	1,404
Wayne	18.6	1,469
Grade at South Logan Creek	19.2	1,470
Bottom of South Logan Creek	19.2	1,452
Northside	31.3	1,643
Summit	34.2	1,809
Hoskins.....	38	1,684
Norfolk	46.5	1,542
Hartington Branch:		
Wakefield.....	0	1,404
Grade at Logan Creek.....	3.7	1,422
Bottom of Logan Creek.....	3.7	1,404
Concord.....	10	1,455
Grade at Logan Creek.....	17.5	1,503
Bottom of Logan Creek.....	17.5	1,490
Coleridge	24	1,672
Hartington.....	33.8	1,404.5
Sioux Falls Branch:		
Junction	181.8	1,633
Summit, grade.....	184.5	1,691
Little Rock River—		
Water.....	187.4	1,629
Bridge	187.4	1,649
Rushmore	190.1	1,665
Adrian	196.9	1,538
Kanaranza Creek—		
Water.....	198	1,499
Bridge	198	1,511
Summit, grade.....	199.5	1,569
Drake.....	203.7	1,516
Elk Slough, grade.....	206.2	1,469
Summit, grade.....	207.1	1,515
Rock River, water.....	210.3	1,423
Luverne.....	211.1	1,451
Summit, grade.....	216.1	1,543
Beaver Creek—		
Station.....	219.3	1,443
Water.....	219.8	1,385
State Line.....	224.4	1,383
Valley Springs	225.2	1,392

Elevations on the Chicago, St. Paul, Minneapolis and Omaha Railway—Continued.

Locality.	Distance.	Altitude.
Sioux Falls Branch—Continued.	<i>Miles.</i>	<i>Feet.</i>
Big Sioux River { low and high water	232.4	{ 1,281
bridge	232.4	1,302
Terrace south of river	234.4	1,363
Sioux Falls	240.2	1,394
Big Sioux River, high and low water	240.4	{ 1,381
		1,385
Summit, grade	241.6	1,471
Big Sioux River, water	243.4	1,403
Skunk Creek—		
Water, sec. 31, T. 102, R. 50	250	1,449
Bridge	250	1,465
Hartford Siding, sec. 22, T. 102, R. 51	254.4	1,561
Summit, grade, sec. 9, T. 102, R. 52	261.2	1,692
East Vermilion River—		
Water, sec. 27, T. 103, R. 53	268	1,455
Bridge	268	1,469
Montrose Siding, close west of last	268.3	1,471
West branch of East Vermilion—		
Water, southwest corner of sec. 15, T. 103, R. 53	269.5	1,468
Bridge here	269.5	1,480
Summit, grade	275.9	1,586
Salem, sec. 13, T. 103, R. 55	279.5	1,517
West Vermilion River, water, sec. 15, T. 103, R. 55	281	1,457
Wolf Creek, water, sec. 20, T. 104, R. 56	290.6	1,370
Fawn Lake, water, T. 105, R. 58	303.5	1,320
Stony Creek, water, sec. 25, T. 106, R. 60	313	1,253
James River, water, sec. 12, T. 106, R. 61	320.2	1,212
Prairie, 5 miles west of last	325	1,276

Elevations along the Dakota Central Division of the Chicago and Northwestern Railway from Hawarden, Iowa, to Iroquois, South Dakota.

Locality.	Station.	Altitude.
		<i>Feet.</i>
Hawarden.....	0	
Crossing, Chicago, Milwaukee and St. Paul—		
Grade.....	18	1, 182
Ground.....	18	1, 179
East bank Big Sioux.....	38	1, 182
Do.....	108	1, 181
Do.....	378	1, 437
Alcester.....	468	1, 355
Do.....	521	1, 320
Do.....	538	1, 344
East bank Brule Creek.....	584	1, 310
Do.....	748	1, 345
Do.....	908	1, 513
Beresford.....	928	1, 505
Do.....	1, 118	1, 340
Do.....	1, 358	1, 240
Centreville.....	1, 463	1, 233
East bank Vermilion.....	1, 487	1, 223
Do.....	1, 528	1, 207
Do.....	1, 538	1, 240
Do.....	1, 953	1, 325
Hurley.....	2, 154	1, 272
Do.....	2, 568	1, 360
Crossing of Chicago, Milwaukee and St. Paul.....	2, 579	1, 335
Grade of Chicago, Milwaukee and St. Paul.....	2, 579	1, 330
Grade of Chicago and Northwestern.....	2, 579	1, 335
Parker.....	2, 627	1, 340
East bank of West Vermilion.....	2, 637	1, 340
Do.....	2, 837	1, 506
Do.....	3, 027	1, 500
Do.....	3, 337	1, 560
Canistota.....	3, 487	1, 555
Salem and crossing of St. Paul, Minneapolis and Omaha.....	4, 017	1, 515
East bank of West Vermilion.....	4, 182	1, 485
Do.....	4, 277	1, 530
Canova.....	4, 662	1, 525
Vilas.....	5, 187	1, 480
East bank of Rock Creek.....	5, 510	1, 426
Do.....	5, 657	1, 466
Carthage.....	5, 857	1, 440
East bank Redstone Creek.....	5, 865	1, 436
Esmond.....	6, 227	1, 430
Do.....	6, 397	1, 450
Do.....	6, 617	1, 425
Iroquois.....	6, 672	1, 400

Elevations along a preliminary survey from Chamberlain, South Dakota, to Lemare, Iowa.

[Furnished by B. B. Colborne, who made it in the interests of the Chicago, Milwaukee and St. Paul Railway. Datum, 300 feet below starting point, which happened to be the bottom (not bottom land) of the Big Sioux River.]

Locality.	Station.	Elevation above datum.
		<i>Feet.</i>
One mile north of Chamberlain, South Dakota, water in Missouri River above sea 1,321 feet.....	-----	221. 95
Chamberlain, station.....	-----	251
One mile east of Chamberlain.....	0	300
Summit, sec. 34, T. 104, R. 70.....	400	505. 7
East end of Red Lake.....	500	450
Water in lake.....	500	440
Bijou Hills Gap.....	1, 300	649. 8
Pratt Creek, water, sec. 2, T. 99, R. 68.....	2, 850	358. 4
Do.....	0	358. 4
Sec. 33, T. 99, R. 68.....	300	492
Summit.....	500	522. 9
Pease Creek, sec. 32, T. 98, R. 66.....	859	395
Summit.....	1, 150	463
West end of Lake Andes.....	1, 400	330
Lake Andes, water.....	1, 400	319. 6
Channel southwest from lake.....	1, 450	326
Between moraine and lake.....	1, 500	342
Choteau Creek:		
Bottom, sec. 29, T. 96, R. 63.....	2, 000	280
Sec. 25, T. 94, R. 62, grade.....	3, 000	184
Sec. 36, T. 94, R. 62, grade.....	3, 050 †	181
Sec. 36, T. 94, R. 62, water.....	0	169
Summit.....	300	327
Emanuel Creek:		
Quarter of a mile above Springfield station.....	600	123
Three-quarters of a mile below Springfield station.....	-----	104
Near station.....	-----	98
Water in Missouri River at—		
Springfield.....	-----	76
Yankton.....	-----	48
Yankton, grade of Chicago, Milwaukee and St. Paul....	-----	64
Edge of river bottom at mouth of Turkey Creek, sec. 13, T. 94, R. 54; station from Springfield.....	2, 200	58
Summit.....	2, 500	227
West edge of Vermillion, second bottom.....	2, 750	110

Elevations along a preliminary survey from Chamberlain, South Dakota, to Lemars, Iowa—Continued.

Locality.	Station.	Elevation. above datum.
Vermilion River:		<i>Fect.</i>
Grade, sec. 23, T. 94, R. 52 (Bloomingdale)	2,950	32
Lower bottom, east edge	3,500	38
Second bottom, west edge	3,150	102
Second bottom, east edge	3,500	148
Brule Creek:		
Sec. 16, T. 94, R. 50 (Emmett)	3,550	105
Water		95
Brule Creek, bottom	3,700	125
Summit	3,850	268
Big Sioux:		
Bottom	4,050	27
River	4,100	0
Railroad crossing at Akron		28
Summit	4,500	277
Broken Kettle Creek, sec. 8, T. 92, R. 47	4,650	158
Summit, sec. 36, T. 92, R. 47	4,850	{ 280 301
Mink Creek	5,100	105
Mink Creek, water	5,100	87
Sec. 23, T. 92, R. 46	5,150	8.6
West Floyd River:		
Grade	5,200	79
Water		60
Floyd River:		
Grade	5,300	84
Water		60
Lemars, 5-10 feet lower than Illinois Central station ..	5,400	95

Elevations on survey north of Lake Andes, from sec. 28, T. 96, R. 63, to Platte Creek Crossing, sec. 2, T. 99, R. 68.

Locality.	Station.	Elevation.
Crossing of Lake Andes, sec. 16, T. 97 R. 64, (water 7 feet deep)	0	<i>Fect.</i> 319.6
Summit north of Lake Andes	500	564.9
Pease Creek	800	487
Summit	1,150	548
Platte Creek	1,450	358

Elevations along the Chicago, Milwaukee and St. Paul Railway in Dakota and part of Iowa, as per profiles in chief engineer's office.

[Furnished by the courtesy of D. J. Whittemore, chief engineer.]

Locality.	Elevation above Lake Michigan.	Elevation above the sea.
	<i>Feet.</i>	<i>Feet.</i>
Sheldon, Iowa	822	1,404
Boyden, Iowa	830	1,412
Patterson, Iowa	842	1,424
Summit west of Patterson	869	1,451
Rock Valley	662	1,244
Junction of Rock Valley	658	1,240
Rock River:		
Track	657	1,239
Water	635	1,217
Inwood	880	1,460
Sioux River:		
Track	657	1,239
Water	635	1,217
Canton	655	1,247
Crossing at Canton Junction	670	1,252
Worthing	772	1,354
Lennox	763	1,345
Vermilion River (bridge)	711	1,293
Chicago and Northwestern Railway, crossing east of		
Parker	736	1,318
Parker	758	1,340
Summit west of Parker	894	1,476
Junction at Marion Junction	856	1,438
Station at Marion Junction	858	1,440
Wolf Creek bridge	830	1,412
Bridgewater	829	1,411
Emery Station	797	1,379
Pierre Creek bridge	720	1,302
Alexandria	761	1,343
James River bridge east of Mitchell:		
Track	629	-----
Water	615	1,197
Station at Mitchell	710	1,292
Junction west of Mitchell	706	1,288
Mount Vernon	822	1,404
Plankinton	937	1,519
White Lake	1,055	1,637
Kimball	1,197	1,779
Pukwana	955	1,537

*Elevations along the Chicago, Milwaukee and St. Paul Railway in Dakota and part of Iowa.
as per profiles in chief engineer's office—Continued.*

Locality.	Elevation above Lake Michigan.	Elevation above the sea.
	<i>Feet.</i>	<i>Feet.</i>
Chamberlain	772	1,354
Missouri River at Chamberlain	739	1,321
Running Water Branch:		
Marion Junction	856	1,438
Freeman	920	1,502
Menno	733	1,315
Station, James River	602	1,184
Bridge over James River—		
Track	598	1,180
Water	587	1,169
Scotland	756	1,338
Tyndall	827	1,409
Springfield	643	1,225
Running Water	629	1,211
Water in river		1,221
Sioux City and Dakota Division:		
Junction near Scotland	772	1,354
Lesterville	793	1,375
Utica	797	1,379
Yankton (Burleigh street)	602	1,184
Bridge over James River—		
Track	586	1,168
Water	570	1,152
Gayville	576	1,158
Meckling	565	1,147
Bridge, Vermillion River—		
Track	559	1,141
Water	538	1,110
Vermillion	559	1,141
Burbank	551	1,133
Elk Point	540	1,122
Jefferson	527	1,109
McCook	521	1,103
Bridge, Sioux River—		
Track	521	1,103
Low water	497	1,079
Sioux City	513	1,095

Elevations along the Chicago, Milwaukee and St. Paul Railway in Dakota and part of Iowa, as per profiles in chief engineer's office—Continued.

Locality.	Elevation above Lake Michigan.	Elevation above the sea.
Elk Point to Sioux Falls Junction:	<i>Feet.</i>	<i>Feet.</i>
Elk Point	540	1, 122
Bridge, Sioux River—		
Track	521	1, 103
Water	507	1, 089
Westfield	540	1, 122
Akron (Portlandville)	564	1, 146
Chicago and Northwestern crossing (Hawarden) ..	587	1, 169
Calliope	591	1, 173
Bridge, Sioux River—		
Track	598	1, 180
Water	571	1, 153
Eden	631	1, 213
Austen	613	1, 195
Fairview	623	1, 205
Beloit	649	1, 221
Bridge, Sioux River—		
Track	648	1, 230
Water	633	1, 215
Crossing at Canton Junction	670	1, 252
Bridge, Sioux River at Sioux Falls—		
Track	804	1, 486
Water	787	1, 369
Sioux Falls	802	1, 384
Bridge over Sioux River at Dell Rapids—		
Track	907	1, 480
Water	879	1, 451
Station, Dell Rapids	901	1, 483
Bridge, Sioux River—		
Track	909	1, 491
Water	894	1, 476
Track	928	1, 510
Water	911	1, 493
Sioux Falls Junction	929	1, 511
Southern Minnesota Division:		
Airlie, Minnesota	1, 070	1, 652
Flandreau	983	1, 565
Bridge, Sioux River—		
Track	938	1, 520
Water	928	1, 510

Elevations along the Chicago, Milwaukee and St. Paul Railway in Dakota and part of Iowa, as per profiles in chief engineer's office—Continued.

Locality.	Elevation above Lake Michigan.	Elevation above the sea.
Southern Minnesota Division—Continued.		
Egan.....	943	1,525
Sioux Falls Junction.....	929	1,511
Coleman, Dakota.....	1,109	1,691
Wentworth.....	1,108	1,690
Madison.....	1,081	1,663
Bridge, East Vermillion River—		
Track.....	1,067	1,649
Water.....	1,040	1,622
Winfred.....	1,122	1,704
Howard.....	980	1,562
Chicago and Northwestern crossing, Vilas.....	888	1,470
Roswell.....	814	1,396
Diana (Artesian).....	727	1,309
Bridge, James River—		
Track.....	652	1,234
Water.....	627	1,209
Forestburg.....	644	1,226
Woonsocket.....	720	1,302
Hastings and Dakota Division:		
At lower station at Ortonville.....	402	984
Bridge, Minnesota River—		
Track.....	383	965
Water.....	370	952
Station, Milbank Junction.....	559	1,141
Summit siding (summit of Coteaus).....	1,415	1,997
Waubay.....	1,225	1,807
Webster.....	1,258	1,830
Bristol.....	1,190	1,772
Andover.....	891	1,473
Groton.....	719	1,301
Bridge, James River—		
Track.....	696	1,278
Water.....	684	1,266
Bath.....	715	1,297
Chicago and Northwestern crossing.....	714	1,296
Aberdeen.....	715	1,297
Mina.....	847	1,429
Ipswich.....	945	1,527

Elevations along the Chicago, Milwaukee and St. Paul Railway in Dakota and part of Iowa, as per profiles in chief engineer's office—Continued.

Locality.	Elevation above Lake Michigan.	Elevation above the sea.
Whetstone Branch:	<i>Feet.</i>	<i>Feet.</i>
Milbank Junction	559	1, 141
Corona.....	584	1, 166
Wilmot	606	1, 188
End of track (33 miles from Milbank).....	637	1, 219
James Valley line :		
Mitchell.....		
Junction near Mitchell	706	1, 288
Letcher	713	1, 295
Woonsocket.....	720	1, 302
Alpena	731	1, 213
Virgil.....	755	1, 337
Wolsey.....	765	1, 347
Chicago and Northwestern crossing (Wolsey).....	764	1, 346
Bonilla.....	750	1, 332
Tulare	729	1, 311
Redfield.....	705	1, 287
Chicago and Northwestern crossing.....	706	1, 288
Ashton	708	1, 290
Mellette.....	792	1, 294
Warner	793	1, 295
Chicago and Northwestern Railway crossing.....	712	1, 294
Aberdeen	715	1, 297
Westport.....	745	1, 227
Frederick	783	1, 365
Ellendale	864	1, 446

NOTE.—In preparing the above statement the elevations above Lake Michigan were determined by reducing the datum lines of the various profiles on file in the office to lake level, beginning at Milwaukee, thence to La Crosse, and thence by four different routes to a common point in Dakota, where it was found that the extreme variation was not more than 5 feet. The elevations given are about an average of the extremes found.—E. O. Reeder, assistant engineer.

Supplementary list.

Locality.	Elevation above Lake Michigan.	Elevation above the sea.
Scotland and Armour line:	<i>Feet.</i>	<i>Feet.</i>
Scotland	756	1, 338
Tripp	974	1, 556
Delmont.....	899	1, 481
Armour	932	1, 514
Tripp and Mitchell line.....		
Tripp	974	1, 556
Parkston.....	811	1, 393
Ethan.....	756	1, 338
Mitchell.....	712	1, 294

Elevations along the Sioux City, O'Neill and Western Railway.

[Obtained through the kindness of J. H. Charles, of Sioux City, from F. C. Hills, receiver.]

Locality.	Elevation above datum.	Elevation above sea.
	<i>Feet.</i>	<i>Feet.</i>
Government bench mark, Sioux City	106.69	1, 111.8
South Sioux City, Nebraska.....	100	1, 106
Jackson	110	1, 116
Siding, sec. 25, T. 29, R. 6. E.....	175	1, 181
Waterbury	280	1, 286
Summit east of Allen.....	515	1, 521
Allen.....	480	1, 486
Summit east of Dixon	550	1, 556
Dixon	445	1, 451
Laurel	465	1, 471
Belden	540	1, 546
Logan Creek, bridge.....	600	1, 606
Randolph	660	1, 666
Summit west of Randolph	825	1, 831
Osmond	655	1, 661
Bridge east of Plainview	640	1, 640
Plainview	668	1, 674
Brunswick	846	1, 852
Savage	860	1, 866
Orchard	920	1, 926
Emporia	965	1, 971
Page	947	1, 953
O'Neill	965	1, 971

Elevations along the Sioux City, O'Neill and Western Railway—Continued.

Locality.	Elevation above datum.	Elevation above sea.
	<i>Feet.</i>	<i>Feet.</i>
Western line of Hall County		2, 338
Western line of Rock County		2, 576
Western line of Brown County		2, 763
Crossing, Middleloup, Cherry County, water level		2, 932
Highest point, R. 33, Cherry County, three-fourths mile east of west line		3, 379
Highest point, R. 37, Cherry County, one-half mile east of west line		3, 658
Western margin of Cherry County		3, 837
Highest point, R. 44, Sheridan County, west line		3, 945
Crossing, Box Butte Creek, Sheridan County, western margin		3, 845

Elevation of the Sioux City and Northern Railroad.

[Through the kindness of S. J. Beals, receiver.]

Locality.	Elevation above sea.
	<i>Feet.</i>
Sioux City, shops east of Division street	1, 109. 6
Dalton, Iowa	1, 212. 5
Struble, Iowa	1, 271. 7
Garretson, South Dakota	1, 496. 1

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DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 159



WASHINGTON
GOVERNMENT PRINTING OFFICE

1899

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

THE GEOLOGY

OF

EASTERN BERKSHIRE COUNTY

MASSACHUSETTS

BY

BENJAMIN KENDALL EMERSON



WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

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LETTER OF TRANSMITTAL.

AMHERST COLLEGE,
Amherst, Mass., July 6, 1898.

SIR: The accompanying work is presented for publication as a bulletin of the United States Geological Survey. It is supplementary to the text of the Housatonic folio of the Geologic Atlas of the United States, and should be used in connection with the maps and sections of the folio.

Very respectfully, your obedient servant,

B. K. EMERSON.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

THE GEOLOGY OF EASTERN BERKSHIRE COUNTY, MASSACHUSETTS.

By B. K. EMERSON.

INTRODUCTION.

The country here described is represented on the Becket and Sandisfield sheets, and in Bear¹ Mountain extends into the area of the Sheffield sheet, of the topographical map of the State of Massachusetts. On the east it adjoins the territory discussed by the author in a recent monograph of the United States Geological Survey.² On the north it is bounded by the Hoosac Mountain area, which has formed the subject of a monograph by Professors Pumpelly and Wolff.³ It is a section across the Green Mountain chain in Massachusetts, a deeply eroded region of pure Appalachian type, composed of sharply folded pre-Cambrian and Paleozoic crystallines.

This territory forms part of a deeply trenched plateau, and along the western border of the area the ground sinks by a steep scarp to the low limestone valley of the Housatonic. Upon the upland the surface is underlain by a series of pre-Cambrian anticlines, more or less overturned to the west, which form an almost continuous band across the State. They are included in a much broader band of Cambrian conglomerate-gneisses. The Cambrian quartzite and the Stockbridge limestone rise somewhat onto the upland from the west, and the Cambrian gneisses dip steeply beneath newer sericite-schists along the east border of the area.

The axes of the folds strike mainly north and south, but in the western-central part of the tract they bend in great curves to the west, even into sickle shape, and in extreme form are overturned and at the same time bent in curves, producing a complex, fan-like structure.

¹ The United States Board on Geographic Names has decided that the name used for this mountain in the publications of the United States Government shall be Bear, and not Beartown. The author of this bulletin states that there are other "Bear" mountains, and that this mountain will always be known in the region as Beartown Mountain.—EDITOR.

² The geology of Old Hampshire County, Massachusetts, by B. K. Emerson: Mon. U. S. Geol. Survey, Vol. XXIX.

³ The geology of the Green Mountains in Massachusetts, by R. Pumpelly, J. E. Wolff, T. Nelson Dale: Mon. U. S. Geol. Survey, Vol. XXIII.

TOPOGRAPHY.

The region under discussion preserves distinctly the form of a plateau. A most striking topographical feature of this plateau is its rapid sinking on the west to a limestone plain 1,000 feet above sea level. Where the limestone penetrates far east into the crystalline area, in Dalton, East Lee, and Tyringham, it is sunk to the same low level as in the open valley to the west, and that this is due to the solubility of the limestone is suggested by the fact that the Cheshire quartzite, much more exposed and softer, is preserved across the central part of Washington fully as far to the east and at a much higher level.

A low crest line runs N. 10° W. through Peru, in the northeast corner of the area considered, rising to 2,295 feet 2 miles south of the center of the town and continuing north as the crest line of Hoosac Mountain (Spruce Hill, 2,480 feet). From this crest line the plateau sinks slightly westward to where its bluffs look down on the Housatonic Valley, with the highest peaks rising from 1,740 feet in the northern part of the area to 2,075 feet in the central part.

In the southern half of the area the bluff which has formed the western edge of the plateau clear across the State extends westerly in Bear Mountain (1,865 feet), facing northward for several miles, and is then lower and less pronounced across the southern half of the area, sinking to 1,750 feet across New Marlboro.

Also in the southern half of the area another broad crest, replacing the first, rises on the west side of the plateau, reaches 2,120 feet in Becket Mountain, and broadens to the south across Tyringham and New Marlboro. These crests sink gradually toward the south. A broad but slight depression, occupied by many ponds, crosses the area between the crests, from Hinsdale to the Otis reservoir.

There is also a southeastward sinking of the level from the second crest line to 1,450 feet at the southeast corner of the area, so that the plateau dips west in its northern half and east in its southern half.

The watershed follows the first crest for several miles, then crosses the depression transversely to the west, and continues down the western crest. This throws most of the drainage into the Connecticut River, though the watershed makes a wide detour to the east around the headwaters of the Housatonic.

This watershed crosses three well-marked wind gaps or valleys, which are not occupied by any water course but from which tributaries of the Housatonic flow northwest and those of the Connecticut southeast. These are (1) the deep canyon between Washington Station and Becket, occupied by the Boston and Albany Railroad; (2) the prolongation of the East Lee Valley at Greenwater Pond; and (3) the less marked upland prolongation of the low Tyringham Valley which connects with the Clam River Valley. These wind gaps form the centers of the three important transverse features of the topography. The deep limestone bay of Dalton is continued in the pre-Cambrian basin of Hinsdale at a higher

level, and this narrows into the Becket Canyon, which is continued in the Westfield River Valley across the whole range. Thus is formed the only passageway for a railroad across the range.

The Dalton limestone bay was caused by the removal of the Stockbridge limestone, which here penetrates far into the mountain mass. East of this bay the greater solubility and consequent erosion of the gneisses and limestones of the overturned pre-Cambrian anticline has caused the broad Hinsdale depression where the anticline is wide; and the same anticline narrows and becomes vertical where it bends southeastward, making the deep canyon which extends from Washington Station to North Becket.

The divide is now at Washington Station, and the Housatonic, coming down from the Washington Hills, flows north across the low depressions here mentioned and swings around to the south, following the larger limestone valley; the Westfield River flows south through the canyon and then southeast until it joins the Connecticut.

From Becket eastward the position of the Westfield is normal, depending on the original southeast slope of the plateau and disregarding the geological structure, except that it seems somewhat influenced by faults. Above this point the structure has controlled the course of the stream from Washington to Becket and forced it into the canyon; and the drainage also seems to have been inverted, that from Dalton, Windsor, and Hinsdale, which formerly went into the Westfield River at Washington, being now carried westward by the Housatonic. If the course of the Housatonic from Dalton south be inverted, nearly all the tributaries on the west would then flow southeast in normal relation to it. A similar statement is true of several of those on the east in so far as they have not come under the influence of the limestone, which has by its solution produced long ponds and deflected several streams into them. Indeed, each lobe of the pre-Cambrian has become the bed of a brook.

The present course of the Housatonic across Hinsdale is complicated by the extensive glacial lake deposits in that town. When the ice had just shrunk away from the uplands and still filled Pittsfield Valley and the Dalton bay, the valley of the Westfield became a main outlet for the glacial waters, which widened above Becket Canyon into a lake across the low ground of Hinsdale and Washington, producing the broad sand flats that extend across this area and the great delta flat which rises just east of Hinsdale station and extends to the Center. Its lobed southward-facing front, swinging in a great loop between these two places, is well marked on the map. The extremely sinuous course of the Housatonic is due to its passage, with slight fall, across these fine sands.

The notch across the mountains seen in the East Lee-Farmington River Valley is formed in a similar way. The Stockbridge limestones project but little into the East Lee Valley of pre-Cambrian limestones, but this valley is prolonged into the Farmington River Valley, which

cuts clear across the range. In its lower third, from New Boston south, the stream runs in a narrow gorge cut by itself without regard to the substructure and controlled by the old surface of the base-level plain over which it began its flow. The middle third is controlled in some degree by the Otis fault (see map, Pl. IX). The northwestern third is controlled similarly to the Hinsdale area, by the solution and erosion of the limestone and the formation of the deep East Lee Valley along the long and narrow anticline which sweeps in a broad curve from East Lee to West Becket.

South of the southern end of Greenwater Pond there is a low divide in the deep valley bottom. South of this point the waters flow into the Farmington River; north of it they flow, by Greenwater Pond Brook, into the Housatonic. This brook seems also to indicate a reversed drainage, as the tributaries make obtuse angles with the main brook and seem to have once been tributary to a southeast stream.

The Dalton phase is lacking here, as the Stockbridge limestone does not penetrate the crystallines.

The great Lenox fault at the foot of the mountains cuts across the mouth of the valley and gives access to it by dropping the western half of the Tyringham pre-Cambrian below the bottom of the Housatonic Valley.

In the Tyringham Valley, next south, the limestones once penetrated far southwest along the Tyringham fault, but have now been mostly cleared out from the deep, narrow valley, which is abruptly closed at its lower end but continues at a much higher level to connect with the transverse valley of Olam River, which joins the Farmington River at New Boston.

One can dimly discern in the Tyringham Valley a fragment of pre-Cambrian topography and its explanation. In the Hop Brook gorge, at the head of the valley, the pre-Cambrian limestones appear as the core of an anticline, which ends, with sharp southeastern pitch, near the mouth of Hayes Pond. This anticline extends along the axis of the valley beneath the Cambrian and appears in its middle at the Brookside mill below the "Cobble," and its erosion in pre-Cambrian times can be said, with considerable probability, to have formed a long, narrow bay, into which the progressive transgression of the Cambrian sea brought first the sand beds of Cambrian times and then the deep-water calcareous deposits which formed the Stockbridge marbles that once filled the valley. The steep southern pitch of the limestone core of the anticline at its south end caused the abrupt termination of the valley in that direction.

In a similar way a curious topographical feature was formed in the basin of Goose Pond. A long, narrow, curved anticline brought the limestone to a level where it could be reached by solution and erosion, and this deep linear depression is the result.

In Monterey the limestones extend again far eastward, and their solution has produced a broad upland valley and a westerly drainage

whose limits are quite closely coincident with the former area of limestone.

Finally, in the southern portion of the area there are many small ponds occupying pre-Cambrian limestone areas and surrounded by Cambrian gneisses, where I suspect that the solution of the limestone has caused the caving in of the gneisses, and that their final removal by the ice has produced these small and peculiar land-locked ponds.

HISTORICAL SKETCH OF THE BUILDING OF THE PLATEAU.

The country is now a central section of a deeply eroded mountain region of Appalachian type, sharply folded, and overturned northwesterly by forces acting from the east.

The pre-Cambrian rocks were folded and eroded—no one knows how much—in pre-Cambrian time, and toward the close of that time a deep north-south depression occupied the position of the present Housatonic Valley, extending far westwardly, and lateral valleys branched from it to the east up the present Tyngham, East Lee, and Dalton valleys.

The great transgression or passage of the waters across the region from the west, which introduced the Cambrian era, admitted water into this valley system, and as it advanced it deepened them so that limestones were formed in the valleys, while just east sandstones and conglomerates were laid down nearer the shore line, and there are many transitions from limestone to sandstone. The waters stretched west to the foot of the Adirondacks and continued east across Massachusetts, surrounding a large pre-Cambrian area which extends from the southeastern part of Worcester County across Connecticut to the mouth of the Connecticut River, and reaching some large land body east of the present coast which furnished the material for the abundant conglomerates that appear in the Cambrian gneiss at Monson and in the Hudson arkose in Hudson and Marlboro and in Worcester County, and stretch far northeast into Maine, marking perhaps an old shore line near which the altered eruptives in the Marlboro region were extruded.

The continued sinking of the land, which sent the shore line so far east, beyond the region here studied, caused the conglomerates to change into sandstones, and these into shales which have now become the Rowe hydromica-schists and which are represented in Worcester County by the Paxton whetstone-schist.

Shales continued to be deposited in the east after the partial uprising of the Stockbridge limestone caused it to be covered by the shales which have become the Berkshire schists and which are continued east in the Goshen and Conway schists, and by the Brimfield schists east of the Connecticut. These may be about on the horizon of the Lower Trenton beds.¹

The increased folding brought nearly all this area above the level of the sea and produced the Bernardston Upper Devonian basin on the

¹ The Washington limestone, by Dr. C. H. Richardson: Proc. Am. Assoc. Adv. Sci., 1898, p. 295.

Connecticut, and the Worcester late Devonian or Carboniferous basin, both apparently opening toward the north.

For the later movement of folding and crushing, the New York horizontal Paleozoic country is the unfolded "foreland" toward which the folds advanced; the "rearland," or country from which the pressure came, has sunk into the Atlantic off the present east coast; the great bands of granite which cross the middle of the State are the eruptives on the concavity of the folded ranges melting up in the great synclines. Here, in the core of the range and a long way west across the foreland, eruptives of the time of the folding are wanting.

The Connecticut and Housatonic valleys are "graben,"¹ or long narrow areas sunk between faults. These faults bound the intermediate block or "horst" which forms the Green Mountain upland. It is simpler to assign them both to the same pre-Triassic era.

Erosion has since worn the mountain range down to its roots, and the "Cretaceous base-level" thus formed may have extended, with some approach to horizontality, across the area and westward, touching the crests of the Taconics and of Greylock and Mount Washington, to the north and south, respectively. If this be true, all the later irregularities would depend upon the unequal capacity for erosion of the two areas, especially upon the solubility of the limestone. The alternative would be that the great depression of the Housatonic limestone valley was in some large part caused by the later downthrow of the limestone area between faults already established. The former supposition seems to me more probable. It would place the downthrow wholly before the Cretaceous base-leveling.

GEOLOGY.

I have distinguished the following subdivisions of the pre-Cambrian and Paleozoic rocks in the Becket and Sandisfield quadrangles, which are described in this paper.

SECTION OF PRE-CAMBRIAN AND PALEOZOIC ROCKS IN WESTERN MASSACHUSETTS.

SILURIAN.

West of the pre-Cambrian.

BERKSHIRE SCHIST.

Chloritic hydromica- or sericite-schist.

STOCKBRIDGE LIMESTONE (upper part).

A white sugary marble, often tremolitic, with included schist and quartzite beds.

East of the pre-Cambrian.

ROWE SCHIST.

Light greenish gray sericite-schist, grading southwardly into a feldspathic mica-schist.

HOOSAC SCHIST.

Dark-gray albitic sericite- (hydromica-) schists.

¹Success, Das Antlitz der Erde.

CAMBRIAN.

West of the pre-Cambrian.

STOCKBRIDGE LIMESTONE (lower part).

CHESHIRE QUARTZITE.

White sugary quartzite, often tourmaline bearing.

BECKET GNEISS.

A light-gray, fine-grained, two-mica- or biotite-gneiss, often conglomeratic, with subordinate beds of quartzite and schist.

East of the pre-Cambrian.

BECKET GNEISS.

A light-gray friable gneiss, often granitoid.

PRE-CAMBRIAN.

WASHINGTON GNEISS.

Rusty, graphitic, and garnetiferous blue-quartz gneiss, becoming fibrolitic toward the south.

TYRINGHAM GNEISS.

Coarse, highly stretched biotite-gneiss, barren of accessories.

LEE GNEISS.

A perfectly banded, medium, black, hornblendic gneiss, sometimes alternating with a white, fine-grained, often micaless, gneiss.

HINSDALE LIMESTONE.

Coarse, highly crystalline, chondroitic limestone.

HINSDALE GNEISS.

Coarse, granitoid biotite-gneiss, often epidotic.

PRE-CAMBRIAN ROCKS.

INTRODUCTION.

A long series of isolated outcrops of pre-Cambrian rocks occupies the western rim of the high ground which extends from north to south across the eastern portion of Berkshire County and looks down on the limestone valley of the Housatonic. They form the axis of the Green Mountains across Massachusetts. (See map, Pl. IX.)

The most northerly outcrops of the pre-Cambrian within the limits of the State are the area of Stamford gneiss of Oak Hill, north of North Adams, and that stretching along the crest of the Hoosac Range south of the tunnel. These have been described in detail by Professors Pumpelly and Wolff, and their relations to the inclosing Cambrian gneiss have been elucidated in a work which marks an epoch in the investigation of the crystalline rocks of New England.¹

The Hoosac area is described as consisting of "a coarse granitoid gneiss which forms the core of Hoosac Mountain proper, occupying the

¹ The geology of the Green Mountains in Massachusetts, by R. Pumpelly, J. E. Wolff, and T. Nelson Dale: Mon. U. S. Geol. Survey, Vol. XXIII.

surface of the mountain for several miles, then disappearing below the overlying rock, but cut in the Hoosac tunnel for nearly 5,000 feet." It is called the Stamford gneiss. It is "a coarse-banded gneiss, composed of long lenticular crystals of pinkish feldspar, flattened lenses of blue quartz, and thin, irregular, greenish layers of a micaceous element (biotite or muscovite, or both) mixed with small epidote crystals."¹ It varies but slightly in microscopic and macroscopic characteristics, and Professor Wolff does not attempt to subdivide it in the field or to decide whether it is an eruptive granite or a highly metamorphosed member of a detrital series.² Specimens have been taken from the material of this age brought to the surface in the central shaft of the Hoosac tunnel to illustrate pre-Cambrian gneissoid granite in the educational series of rocks distributed by the United States Geological Survey.

All the other outcrops of the series are described in this bulletin, beginning with the Hinsdale area in the Becket quadrangle, which is traversed by the north and south portion of the Boston and Albany Railroad, and extending south across that and the Sandisfield quadrangle. The series continues southwest across Connecticut and New York to the Highlands. Several of these areas extend a little way over into the Sheffield quadrangle on the west, and Professor Hobbs thinks that the Cambrian gneisses are worn through, exposing small areas of the pre-Cambrian, on Warner Mountain in Great Barrington and on Brush Hill in Sheffield. The Oanaan Mountain pre-Cambrian enters the Sheffield quadrangle, but not the State of Massachusetts. There are thus twenty-three pre-Cambrian areas in the western part of the State.

These areas change progressively as they cross the State. The Hoosac Mountain area is a monotonous mass of coarse porphyritic, granitoid gneiss of doubtful, but probably eruptive, origin.

The Hinsdale area is a closely appressed and slightly overturned anticline, exposing a nucleus of ancient epidotic gneiss surrounded by a thick bed of highly crystalline, chondrodite-limestone, and this by a band of dark gneisses, while the series is closed by a rusty graphitic blue-quartz gneiss. The whole is in apparent conformity, and no striking unconformity marks its contact with the surrounding Cambrian gneisses. On the west of this anticline the blue-quartz gneiss alone is exposed in the Dalton anticline as the core of a normal fold, in sharpest unconformity to the Cambrian conglomerate.

Widely separated on the east, the Coles Brook limestone band is thrust up irregularly through the Cambrian gneisses. It is extremely long and narrow, and the dark East Lee gneiss accompanies it at its southern end.

To the south of these the broad Tyringham area shows extensive bands of a barren and monotonous coarse biotite-gneiss (the Tyring-

¹ Loc. cit., p. 45.

² Loc. cit., pp. 47, 48.

ham gneiss) characterized by such extreme stretching that the biotite masses are drawn out into long pencils, and foliation surfaces of the rock appear as if fingers had been dipped in ink and drawn across them. This is bordered by the Washington blue-quartz gneiss, the upper member of the series, and strips of this rusty blue-quartz rock are infolded as synclines in it, while the East Lee dark-banded gneiss appears as anticlines. When the latter is worn through, the limestone, or the pyroxene-wernerite or actinolite rock which represents it, appears. In the northern part of the Tyringham area the pre-Cambrian is in apparent conformity with the Cambrian gneisses above, but in the southern part it is in plain unconformity with them. In the latitude of Otis village the blue-quartz gneiss begins to be fibrolitic, and this character becomes more and more pronounced toward the south. The broad Sandisfield area is a low dome which scarcely exposes anything except the Washington gneiss—there a rusty fibrolite-gneiss rarely showing blue quartz and allanite, which extends into Connecticut and carries small beds of chondrodite-limestone.

Finally, in the small areas to the southwest, which are exposed by the solution of the limestone and the sinking and removal of the Cambrian gneisses, the rock is still more strongly ferruginous than farther north, and much magnetite, pyrite, and pyrrhotite appear.

From Campbell Falls south long bands of a dark schistose biotite-gneiss occur, which are full of rounded nodules of microcline largely changed to muscovite and full of fibrolite. The same occur in the southern part of the Sandisfield band.

This change in the character and arrangement of the pre-Cambrian rocks has had a marked influence upon the topography of the range throughout its course across the State of Massachusetts.

In the solid block of the Stamford gneiss the pre-Cambrian composes the crest of the mountain range, while farther south its limestones have by their solution formed all the passes across the mountains and many rock-bordered ponds.

HINSDALE ANTICLINE.

A large portion of the towns of Hinsdale and Washington is occupied by this area of pre-Cambrian rocks, which form an anticline closely appressed and slightly overturned to the west. It is 12 miles long and 4 miles wide. For the greater portion of its length its axis is north and south, but it narrows at its southern end and bends southeastward in sympathy with the Tyringham anticline, ending in the river bed a mile below North Becket station. It also sends an irregular fold southwestward past Washington Center. To the north it ends in several lobes projected far into the town of Windsor.

The east-west fault which limits the Dalton anticline on the south extends far into the center of this anticline and nearly bisects it. As a result, it is much more sharply folded to the south of this fault,

forming a compensation for the fold of the Dalton anticline, which is only partly continued in a slight fold south of the east-west fault.

The Hinsdale anticline is taken as the type of the pre-Cambrian areas, since it is the only one which exposes a gneiss older than the Hinsdale limestone and the one which shows the pre-Cambrian rock series in the fullest way. For this reason the names of the different subdivisions have been mainly drawn from this tract.

HINSDALE GNEISS.

This rock emerges from beneath the Hinsdale limestone and lies in the bottom of the Hinsdale Basin. The upper pre-Cambrian gneisses and, in an even more marked way, the Cambrian gneisses form an unbroken line of high hills around it on every side.

The great area of deeply rotted rock which surrounds the Washington station and which was sheltered from the erosive action of the ice suggests that the whole basin was deeply decomposed at the beginning of the Glacial period and was thus in part excavated by the ice.

The only place where it can be studied in considerable outcrops is on both sides of the roads forming a square a mile north of Hinsdale Center. The commonest rock along the western road of the square is a light-colored, well and coarsely bedded, epidote-biotite-gneiss (see detailed description, page 23, and fig. 1 of Pl. I, p. 26). The large, curved-faced feldspars are mostly crushed to a granular mass, and the result is a rock somewhat like the white Cambrian gneiss, but much firmer and coarser and often showing muscovite of secondary origin on the foliation faces. Other beds are compact and massive and show some blue quartz, which is rare in the Hinsdale gneiss.

Farther north along this road the rock is a coarse granitoid feldspar-quartz mass, rudely foliated by distant biotite-epidote films, and in places strongly stretched. Rocks of this type extend north into a great double-topped hill and make up its western crest.

A peculiar altered limestone bed about a rod thick can be followed from north to south along the top of this western crest. It is mostly changed to silicates, among which tremolite in coarse blades forms beautiful cabinet specimens, and a green clinocllore in coarse plates is very abundant. It is in places broken up into a series of great lenses which run along the strike. This is plainly a result of the solution of part of the limestone and the compression of the gneiss around the remnants. One of these lenses is a mass of hornblende-pyroxene-epidote-calcite rock with cozoön structure.

This limestone appears north of the road running southeast from the center of Hinsdale, near the creamery. The rock is a rusty thin-bedded gneiss, with traces of a layer of limestone, now almost wholly changed to a coarse salite-actinolite-graphite-calcite rock. A shaft was sunk 16 feet deep on this rock in 1885, in search of graphite, and later, in 1895,

more digging was done at the same spot in search of iron. The adjacent rock is exceptional on this horizon, and resembles the Washington gneiss which surrounds the basin as the newest member of the pre-Cambrian series. It lies in the middle of the anticline.

On the eastern road of the square, layers of very dark gneiss carrying much biotite and hornblende alternate many times with the common gray biotite-gneiss and are shot through by small pegmatite veins.

This structure is very characteristic across the eastern peak of the double hill already mentioned. Bands of the two rocks only 3 to 10 inches thick and preserving their widths for long distances, alternate regularly, and the lighter rock weathers more easily into deep grooves, bringing out strongly the continuous strike or in places the great contortions of the bed. This bed can be followed south about 2 miles.

The most interesting type of the Hinsdale gneiss and the most accessible outcrops are 50 rods north of Hinsdale station, on the west side of the railroad. The gneiss rests directly upon the limestone, the rocks being there overturned, and dips 35° SE. It is a peculiar, fresh, coarse gneiss of very white color, although it contains a jet-black biotite in considerable quantity. (See detailed description below.)

These rocks seem characteristic of the horizon just under the limestone, and there is a similar curious rock developed on a similar horizon at the northwest corner of the square of roads mentioned above. It is a coarse flesh-colored gneiss made up almost wholly of feldspar, with a foliated structure imparted by widely separated streaks and flat blotches, all stretched in a common direction and containing a dark-green fibrous hornblende, epidote, and dark-brown titanite.

Structure.—There is a marked prevalence of northerly strikes and moderate easterly dips in the structure planes of the coarse gneisses, and when separate beds can be traced they take the same direction. This agrees with the posture of the limestone bed which surrounds the Hinsdale gneiss.

If the limestone bed at the creamery is an integral part of the series, it is not improbable that the whole may be of sedimentary origin. It makes, however, the impression of a very coarse and not greatly altered granite.

PETROGRAPHICAL DESCRIPTION.

Biotite-microcline-gneiss.—Fifty rods north of the railroad station at Hinsdale is a coarse, white, biotite-epidote-microcline-gneiss of granular texture. In its lower layers the fresh black biotite is in widely separated films mingled with epidote grains. In its upper layers the biotite is aggregated into flattened lenticular biotite-epidote masses, placed an inch apart in the foliation planes. The mass of the rock is a dull white mixture of much feldspar and a little pale bluish quartz. It contains pyrite in small pentagonal dodecahedrons and submicroscopic zircons of a dark clove-brown color. The feldspar which forms nearly the whole mass of the rock is uniformly microcline in large cleavage

pieces, which are granulated at the border and included in broad patches of the granulation mosaic. The remaining fragments are strongly and regularly curved in the cleavage faces, but show no trace of the intergrowth of albitic bands. Sections parallel to OP (001) show with the lens small, rounded, opaque spots, which on examination prove to be bodies placed in the intersection of the two twinning systems. They are cylindrical, with rounded ends, and seem to be muscovite crystals elongated parallel to the *c* axis and slightly twisted; often a slight, lateral pressure has changed them into a pile of overlapping scales. An immense number of epidote grains, small crystals, and microlites, and many minute-lobed plates of biotite are evenly distributed. This multitude of inclusions causes the opaque-white look, but there does not seem to be any trace of kaolinization or weathering. It is epidotization due to metamorphism proper.

The feldspar has the complete microcline structure and pronounced prismatic cleavage, and large patches are still untwinned microcline.

The quartz contains a few short, straight, black microlites unlike the long rutile trichites of the granites. The trains of cavities are very abundant, and often run through several grains of quartz, suggesting crushing. They are made up of very small cavities with motionless bubbles unaffected by heat.

Biotite-gneiss and granulite.—Following the railroad a few rods north from the outcrop of the white gneiss described above, one finds in the wall of the railroad cut an outcrop of a dark-gray, stretched, granitoid gneiss of more normal texture and somewhat finer grain than that last described, which abounds in minute garnets, so that as the mica disappears from some layers they become a light-colored granulite.

Under the microscope it is very unlike the former rock. Microcline is almost wanting, and the mass of the rock is a quartz mosaic of irregular grain, with little microcline and orthoclase, with very wavy extinction, and with a triclinic feldspar near albite. The dark olive biotite is raveled out at the edges and changed to chlorite. The small, round, red-brown garnet grains are generally without inclusion and are non-polarizing. The only remarkable peculiarity of the rock is that large grains of quartz and plagioclase have their centers full of blebs of garnet, quartz, and biotite, while there is entire freedom from nodules or water bubbles. There is every sign of rapid crystallization.

Epidote-gneiss.—Next above the preceding rock is a coarser gneiss, in which greenish layers of biotite, mixed with much green epidote and secondary chlorite in broad, distinct sheets, inclose a fine granular mosaic.

In sections cut across the foliation the microscope shows this mosaic to be made up of elongate-opaque patches, with intervening transparent portions. The latter are a quartz mosaic; the former are portions of a feldspar so filled with minute pale-green epidote that the character of the feldspar can not be determined. The frequency of crushing is

PLATE I.

PLATE I.

FIG. 1.—Hinsdale gneiss, from near N. B. Whitman's house, in the northern part of Hinsdale. The lighter quartz bands are drawn with polarized light to obtain the boundaries of the grains in the mosaic. The darker bands of plagioclase are drawn with common light to obtain a clear view of the minute epidote, biotite, and chlorite crystals. $\times 14$.

FIG. 2.—Washington gneiss, Peru; H. A. Messinger farm. (Slide F.) The granular bands represent a fine quartz-feldspar mosaic, in which much newly formed muscovite is regularly disseminated in fine scales. The intervening bands are of limpid quartz, which is little fissured. The slide is drawn with polarized light and the strong undulose extinction of the quartz bands is represented by shading. $\times 14$.

FIG. 3.—Washington gneiss, Washington, north line of Pittsfield road. Three bands of a quartz-feldspar-muscovite mosaic (F) and a central biotite-muscovite band (B) are separated by three bands of blue quartz (Q) in the dotted portion of which (Q') the blue color has been discharged. A well-defined rhombohedral cleavage appears in part of the quartz. $\times 3$, natural light.

FIG. 4.—A portion of the lower part of the upper-quartz band of fig. 3. The dotted portions (Q') do not show the blue color, but are not otherwise distinguishable, and the cleavage lines run through both portions. $\times 14$, natural light.

FIG. 5.—The above slide (fig. 4) seen with polarized light, showing the coincidence of the crushed and colorless portions (Q') and of the parts with undulose extinction and those with the blue color (Q). The cleavage lines make an angle of 74° instead of 94° , and the oblique position of the axial cross agrees with this decrease of the cleavage angle.

FIG. 6.—Cyanite (K) changing to muscovite (M) with included garnets (G). Becket, p. 84.



1



2



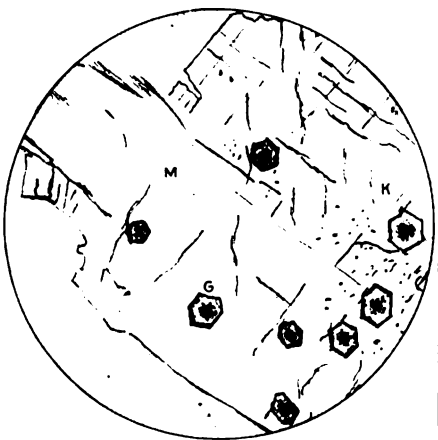
4



5



3



6

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shown by the sheets of cavities passing through the quartz grains. These cavities rarely show bubbles, and only the smaller show motion. When heated to 70° C. they are not changed.

Blue-quartz gneiss.—At N. B. Whitman's house, in the north part of Hinsdale, is a granitoid gneiss (Pl. I, fig. 1) in which the small distant aggregates of black biotite and epidote do not much aid the foliation. Pyrite is abundant. Bands of blue quartz, about 1 to 3 millimeters wide and about twice that distance apart, run interruptedly through the rock; they have crushed borders or dissolve entirely into a white mosaic. Between these is an opaque white mosaic of feldspar crowded full of minute epidotes.

The quartz mosaic represented in the figure by the two broad light bands is very fresh. Sheets of minute pores or solid particles pass from grain to grain. Many of the grains have a delicate wavy extinction. The feldspar, which crosses the figure in three bands, is much coarser, and the feldspars are uniformly a plagioclase with extinction 2 degrees to 12 degrees, generally very low, indicating an acid plagioclase. It is very fresh, and the small sharp epidote, biotite, and chlorite crystals are spread evenly over the field, like the small crystals in a micro chemical experiment, giving the band a glistening, satiny look in the thin section. There is no indication of decomposition, but rather of an original formation of the feldspar mass made up of large allotriomorphic grains, a fissuring of it, a subsequent formation of blue quartz in the fissures, and a later mylonitic effect upon the whole. It is interesting that there is here no trace of microcline or orthoclase, but that the abundant growth of the small, sharp epidote, biotite, and chlorite crystals appears equally well in the plagioclasic as in the microcline-bearing rock, and seems in both to be a result of intercrystallization rather than a secondary alteration of the feldspar.

HINSDALE LIMESTONE.

In the more regular portion of the syncline across Hinsdale so many outcrops of the rock have been found that it is quite certain that a heavy band of limestone, often changed in whole or in part to amphibolite, steatite, or serpentine, encircles or did once encircle the lowest gneisses. It is marked by a series of abandoned limekilns, and before the opening of the "Western Railroad" was of economic value. Several of its outcrops were mentioned by President Hitchcock, and Professor Dana¹ called attention to the locality at Hinsdale Station as containing chondrodite, and from this fact assigned these rocks to the Archean—that is, to the pre-Cambrian.

As exposed in the railroad 50 rods north of the Hinsdale station the limestone is a very coarse, wholly crystalline rock—a white coccolite-limestone containing graphite, chondrodite, phlogopite, and coccolite

¹ Am. Jour. Sci., Vol. XXXIII, 1887, p. 275.

in grains, and hornblende in larger masses, some of which are a foot across. Only 25 feet is exposed, and it is covered by the coarse Hinsdale biotite-gneiss. A mile south, where the highway crosses the railroad near a bridge, the bed reappears and continues for a long distance southward by the roadside, more than 100 feet in thickness being exposed. It is here a very coarse crystalline limestone, the grains often 50 to 100 mm. across and multiple twinned, with crystals of bronzy and pink phlogopite 20 to 30 mm. across, and black to pale-green hornblende, clove-brown pyroxene, green coccolite, graphite, and pyrite. It is in places changed into great masses of matted pale-green tremolite, and this can be followed a long way southward as a very impure tremolitic limestone. It appears as a phlogopite-limestone farther south, at the E. Cheesman place, a half mile west of the next railroad crossing. From this point the bed is covered for a long way south, and I have located it approximately on the map by fixing the boundary between the coarse Hinsdale gneisses and the upper rusty gneisses and also by the fact that its course is marked by abandoned limekilns and ponds and swampy areas where it has been deeply dissolved. In the second cut south of the Hinsdale station are great boulders of serpentine which came from some portion of the bed.

Just east of Muddy Pond, north of Washington Station, the band is represented by the old graphite mine of Washington (see fig. 3, p. 36), which reminds one, except for the size of some constituents, of the graphite vein at Ticonderoga. It contains very coarse calcite, graphite in broad hexagonal plates, coarse white salite, coarse green pyroxene and hornblende masses, groups of finely terminated pistachio-green pyroxene, brown sphene, periclinal, adularia, and garnets, followed paragenetically by coarse calcite with phlogopite, and this by quartz. This has been opened 6 rods along the strike and a shaft sunk 25 feet.

A hundred yards of a fine-grained compact gneiss containing much ilmenite, which I associate with the older gneiss, separates this deposit from a thin bed of limestone on the east; these two beds can be traced south, and cross the road, beneath the two most easterly houses on it, as two beds of amphibolite. South of the pond the outcrops are good, and but a single bed of a pyroxene-hornblende rock can be found as the representative of the united beds, and this swells and contracts in a series of great bunches, due to the removal of most of the limestone by solution.

A remarkable outcrop occurs in the eastern band, 50 rods west of the house of O. Bills and 150 rods east of the southernmost railroad crossing in Hinsdale. Here great layers 3 feet thick are made up almost exclusively of red chondrodite and bright-green clinocllore, the latter in plates up to an inch across, and the change into serpentine and talc has taken place on a large scale.

Farther north, at River Bend Farm, below the mill pond on the Housatonic branch, the limestone is exposed at the sawmill with a

thickness of 600 feet and the base is not seen. At top the bed is changed into a compact, firm, granular, apple-green talc for a thickness of 50 feet, and dark-gray slaty serpentine appears here also in boulders. It is divided by a narrow band of gneiss. The limestone is marked by distant partings of phlogopite and much of it is a fine white marble, faintly banded by dark interrupted streaks. Other extensive outcrops occur farther north, but add nothing to the petrographical characteristic of the rock.

The bed can be traced up to the southern end of the Ashmere reservoir, and the long, deep depression occupied by this pond may be taken as its continuation, and the ruins of an old kiln may be found just beyond the north end of the pond, on a rusty calcite-garnet-hornblende rock.

A mile and a half north, on the northern branch of the Housatonic, is E. Cady's lime pit. Extensive excavations have been made in a bed



FIG. 1.—Section at iron bridge, Windsor. LG, Lee gneiss; HL, Hinsdale limestone; HG, Hinsdale gneiss.

of coarse limestone which has strike, N. 20° E., dip, 45° E. at its south end, and strike, N. 10° W., dip, 65° E. at the north end, where the bed is 83 feet thick, including one rod of coarse hornblende-gneiss. The limestone contains much hornblende and phlogopite. One layer of a dark amphibolite is two inches thick with the bedding.

A most interesting outcrop occurs farther north on the Hinsdale-Windsor road at the iron bridge. This is at the apex of the north-eastern lobe of the limestone. (Fig. 1.) A sharp fold of the overlying gneisses exposes the limestone in a narrow band which runs up from the last locality, and whose apex is exposed here on the bank of the brook. The older gneiss upon which the limestone rests appears beneath the latter at the level of the brook and the newer gneiss (the dark Lee gneiss) arches with many faults over the coarse white limestone, and it is very clear that there has been much solution of the latter and adjustment during the folding of the rocks. The Lee gneiss is a white crushed gneiss with large blotches of hornblende and allanite. The

allanite is especially abundant beneath the bridge, and the hornblendic rock appears as a thick bed of a massive black, heavy, white-spotted gneiss in the fine cliff across the road to the west.

To the west of this outcrop is the high hill of black, crumpled, fine-grained mica-schist (phyllite). The lobe of pre-Cambrian rocks which runs up the east side of this hill is matched by a similar lobe running up the west side, and the curved reservoir pond seems to lie in the continuation of the limestone.

The dam at the outlet of the pond is a wavy bed of dark-green amphibolite, which still contains a central band, 1 to 5 feet thick, of coarse crystalline limestone.

A little farther down the brook, and easily reached by a footpath from the Windsor or Wakonah Falls, is an extensive bed of steatite. Here the limestone bed has changed through actinolite into steatite (fig. 2), and the influence of the removal of the limestone is clear. The steatite has been worked out of great chambers, the back walls of which are composed chiefly of gneiss. The gneiss layers can be seen to be



FIG. 2.—Steatite quarry near Windsor Falls, Hinsdale. Gneiss folding round a bed of steatite.

very complexly corrugated in the immediate vicinity of the steatite, and at the left of the figure they bend at right angles and run, with many corrugations, down the whole end of the steatite bed, cutting it off completely. The strike here is $N. 30^{\circ} E.$ with the plane of the figure, and the dip is $50^{\circ} E.$, or from the observer. The gneiss is the white-and-black banded Lee gneiss. Its position plainly indicates that it has been crushed in around the remnant of the limestone bed spared from solution and sharply faulted.

Upon following the limestone $S. 30^{\circ} W.$ a half mile, to the point where it runs into Dalton and crosses the east-and-west road south of P. Mitchell's, it is seen that the boundary line soon begins to be marked by a great number of serpentine boulders. Thirty rods north of the residence of D. J. Pratt a great bed of serpentine $3\frac{1}{2}$ rods wide has been quarried and is exposed. It is very dolomitic and slaty; much of it is still matted tremolite and actinolite. It sometimes shows a rich nickel-green color, but is much fissured and worthless.

From this point the limestone bed is concealed, and I have followed

it, by boulders and by the strike of the adjacent rocks, for a long distance southeast. It occupies—and its removal has, I think, caused—the deep depression at the north and east foot of the high, rocky hill a mile north by east from Hinsdale Center.

The bed appears beside the western road of the square mentioned in describing the gneiss,¹ in a deep excavation several rods long, with an exposed thickness of 20 feet. The black Lee gneiss is in place just west, and to the east is the peculiar titanite gneiss mentioned on page 23. The limestone is a very pure white, coarse crystalline rock, with small bright coccolite grains and much shining black mica. It is peculiar that this mica is arranged in long streaks and blotches in distant planes and exactly simulating the white, stretched gneiss which occurs so commonly just below the limestone.

It is not until we reach the blind road which runs up onto the hill from near the cemetery at the center of Hinsdale that we again come to ledges showing traces of the limestone band; but the Lee gneiss, which is its constant associate, can be followed almost continuously in the high ground of the hill. In the head of the brook bed east of the second house on this road appear great boulders, apparently almost in place, of an actinolite-limestone which fixes the position of the bed.

PETROGRAPHICAL DESCRIPTION.

Chondrodite-limestone.—At Hinsdale, north of the railroad station, is a limestone which ranges in color from white to pink, a rather coarse (grains 3–5 mm.), highly crystalline rock, with a certain translucency in the grains which immediately distinguishes it from all the other limestones of western Massachusetts and allies it to the limestones of the Adirondacks.

It carries coccolite, phlogopite, biotite, actinolite, chondrodite, pyrite, and magnetite. Generally the coccolite or the chondrodite, or both, are so abundantly and evenly scattered through the mass that it deserves the name coccolite-limestone or chondrodite-limestone, and the accessory minerals are so arranged as to give the mass a distinct foliation, especially where the chondrodite and biotite predominate.

The chondrodite is disseminated through the rock in yellow patches, elongate and parallel to each other, and as in places it changes into black patches, by the admixture of a green mica and magnetite, the resemblance to the boltonite from Bolton, Massachusetts, is striking, especially in specimens of the latter which are changing to serpentine. In large masses it is a rich deep red, like the chondrodite from the Tilly Foster mine. Under the microscope the patches of the mineral are seen to be composed of crystalline grains, fresh and free from inclusions and wrapped around by scales of a pale-green micaceous mineral, without any indication that the one mineral has been derived from the other. The mineral shows strong dichroism, honey-yellow to

¹ Lat. 42° 28'; long. 78° 6'.

deep red-brown. Toward the surface of the ledge the chondrodite weathers to a honey-yellow, opaque, serpentinous mass.

The phlogopite is in small, thick crystals with rounded borders, and has exactly the same bronzy color as the phlogopite from Templeton, Canada. Its crystals are generally surrounded by a band of scales of greenish-gray biotite. Both minerals are fresh, and there is no indication of a transition of one into the other. It has often a beautiful peach-blossom color.

The biotite is often in black scales, at times in isolated crystals with rounded contours, at times bordering the phlogopite in greenish-gray matted scales.

The pyroxene occurs in dark-green grains of coccolite scattered through the limestone, and in small, stout, limpid, emerald-green prisms in the pink variety of the rock.

The magnetite occurs in small crystals and crystalline grains, often associated with the chondrodite; the pyrite is always in small complex crystals.

An analysis of a specimen of this limestone, made in the laboratory of Amherst College by Mr. F. H. Fitts, is here given:

Analysis of chondrodite-limestone from Hinsdale Station.

	Per cent.
Insoluble in HCl	21.96
CaO	41.81
MgO	1.87
FeO	.06
CO ₂	34.71
Total	100.53

Actinolite-limestone.—Forty rods north of Hinsdale station, in the canal beside the stone mill, there is a green massive rock of medium grain, showing a paler green massive pyroxene, a darker green fibrous hornblende, and much pyrite.

With the lens the slide shows little chlorite and much epidote, and in a few places the colorless ground appears. Under the microscope this colorless ground proves to be a much-twinned calcite, into which the terminations of the epidote crystals project. Large colorless areas of pyroxene are intergrown with the hornblendic mineral, which varies in appearance from actinolite to tremolite.

In the Massachusetts survey collection No. XV, 168, is a vein or layer of siliceous calcite in gneiss, labeled "Augitic gneiss, Washington, NW. part." It contains a dark-green fibrous hornblende in large blades, derived apparently from a light-green pyroxene which exists in remnants, and also from crystals of a dark-brown titanite.

LEE GNEISS.

The type of the Lee gneiss is found in the hill overlooking East Lee on the northeast, where the rock is a heavy-bedded black gneiss. It is often a flat-bedded black gneiss, alternating in thin layers with a white, sugary granulite.

The most accessible outcrops of this rock along the western side of the area are in the bed of the river near the stone mill just north of the Hinsdale station. The light and dark banded gneisses are tough and granitoid, and abound in epidote to an unusual degree. Several varieties of the rock can be studied at this locality:

1. A light-gray, flat, and thin-foliated biotite-gneiss, so much like the newer, friable Becket gneiss that one is surprised at its toughness.

2. A coarser gneiss, with the greenish biotite segregated into broad, distant sheets and containing thin, lenticular layers of a coarse, reddish granite. Under the microscope the bands of granular quartz are separated by bands of granular epidote, which seem to have wholly replaced the feldspar. The biotite layers often contain much epidote and a secondary green chloritic mineral. The trains of pores run through several quartz grains and rarely show bubbles; only the smaller bubbles show motion.

3. A flesh-colored, thin-foliated gneiss, with greenish films and membranes of biotite, breaking with much difficulty and with little regard to the foliation. This grades, by the entire change of the feldspar, into a quartz-epidote rock.

The Lee gneiss occurs in fine and typical development in the high ridge that extends 2 miles north from Hinsdale cemetery. It includes heavy amphibolite beds and alternating bands of a white granitic gneiss, with distant blotches of hornblende.

By following the main road north from the cemetery a little way past the top of a small hill, 1,040 feet high, large outcrops may be seen in the open field to the left, and here the coarse, white, greatly crushed granitoid beds are distinctly blotched by biotite, and by stretching the biotite is extended in long bands. The rock abounds in blue quartz, while one large amphibolite layer sends off apophyses into the gneiss like an eruptive. Northward, on the crest of the hill 1,720 feet high, the exposures are abundant and the true sedimentary structure is found, together with the secondary foliation produced by pressure. The two have uniformly the same strike, and the latter has generally a lower dip to the west than the former. At the quarry opposite the entrance to Windsor Falls the rock is extremely thin and fissile and superficially resembles the quartzite, but it is really a very feldspathic crushed rock, and carries the dark-green amphibolite beds which are common in the Lee gneiss.

On the Hinsdale-Windsor road, along the east side of the schist area, the rock is greatly rotted in ledges by the roadside, and a little beyond, at the iron bridge, it contains beds of a curious white granitic rock

with coarse, distant hornblende blotches, while the same rock appears in picturesque ledges in the bluffs to the west.

In contrast with the broad area in the western limb of the anticline north of the Warner Mountain fault, south of this fault the Lee gneiss has a thickness of only 20 rods on the surface, and is concealed from this point south to the hill three-fourths of a mile southeast of Muddy Pond (see fig. 3, p. 36), where it is typically developed, and runs around south of Washington Station and the swampy ground, extending north therefrom in such a way as to render probable the presence of the Hinsdale limestone to the north.

TYRINGHAM GNEISS.

Along the west of the Hinsdale anticline the higher beds are faulted out of sight; along the east they are so covered that the Tyringham gneiss can not be mapped or found with certainty. At the south end of the area it comes in with great force and in most interesting and typical development.

At the deep cutting south of Washington Station the rock is a garnetiferous zircon-bearing biotite-gneiss of coarse fibrous or woody texture, rarely containing great blotches of a shining black hornblende. The biotite scales are wrapped around long quartz pencils, so that it is easy to note the dip and yet difficult to detect any planes of bedding. This peculiar structure of the rocks seems to be an extreme of the stretching common in the gneiss of the Cambrian series, especially east of the Connecticut. It was deformed under the influence of compressive forces which permitted flow in a single direction only. It weathers into a mass of quartz-feldspar rods, which are sometimes several inches long. This weathering is in itself quite exceptional. On the hillside above the cutting and along the road going south, large outcrops of the rock appear; it is crumbling into a mass of coarse granitic sand, and in the long cutting, which is in many places 10 to 12 feet deep, the decomposition extends everywhere below the bottom. This is a protected portion of the pre-Glacial weathering.

The wind blows the decomposed rock away like sand, exposing quartz veins and leaving large, rounded nuclei on the surface. The decomposition brings out in strong relief the peculiar structure of the rock as it falls apart into a pile of quartz-feldspar pencils, or long, flat rods—the expression of the perfect stretching of the fresh rock.

WASHINGTON GNEISS.

The broad outer zone of this large anticline is formed by a rusty graphitic blue-quartz gneiss. It is in the main a biotite-gneiss, rusty from the decomposition of pyrite, pyrrhotite, ankerite, and hornblende.

It has associated beds of a heavy, black hornblende-garnet-gneiss which have been taken for emery, and in the whole circuit graphite is a never-failing accessory, especially in the upper portion, and it is occasionally so abundant as to tempt mining.

Another equally persistent and very curious constituent of these gneisses is a blue quartz in flat laminae, 1 to 2 millimeters in thickness, which has often a deep tint of rich, purplish blue. It is so abundant as to form more than three-fourths of the mass, and furnishes very attractive cabinet specimens. Allanite is also a characteristic and abundant constituent of the rock, especially in its upper portion, and the puckering surrounding its black or red cross sections constantly calls attention to its presence in the rock.

In every part of the circuit of this anticline, and along the broken crest of the Dalton anticline, I have never failed to find beneath the next succeeding Cambrian conglomerate-gneisses all these characteristics of the top of the older series. Especially down the eastern side, the area above the limestone is marked by several broad bands of the rusty rocks, with intervening bands of biotite-gneiss. The latter rock is often so crushed that it is with difficulty distinguished from the Becket gneiss above, but there is not such a complete transition from the older gneisses into the white gneiss¹ as that described in the Hoosac area. The rusty blue-quartz gneiss is generally a membranous ("flaserig") rock. Nearly continuous sheets of mica scales wind in and out and inclose the blue-quartz lenses and laminae. When this rock is involved in a crushing later than the formation of the blue quartz, the latter becomes gradually disintegrated at the edges and at last changes to a mosaic of small grains, and the pale-blue tint is lost in the reflections from the many fissures. By a careful search one can usually detect nuclei which show the color, and in this search the pocket lens is a great aid, as the blue color is thus easily distinguished from the blue grays of the quartz from the granites and Cambrian gneisses.

The Washington graphite-gneiss is absent along the whole western side of the syncline, being concealed by the fault and by the westward thrust of the body of the syncline against the resistant mass of the Dalton syncline, until the south boundary of the latter—the Warner Mountain fault—is reached. South of this fault, at the Plunkett reservoir, the Washington gneiss appears, with a width of 2 miles, extending from the top of Warner Mountain, where the Becket conglomerate-gneiss can be seen dipping beneath it, to the top of the low hill which overlooks the great limestone bed 30 rods south of the bridge a mile south of Hinsdale. Its great width is attributable to its low dip eastward and its many undulations. It gradually narrows southward, and in the high hill three-fourths of a mile west of Washington Station it bends westward and forms the great loop which extends west past Washington Center, where it can be conveniently studied.

It is everywhere a coarse muscovite-gneiss, with some biotite, and so abounding in pyrite that it rots into a mass of rusty fragments, and is usually rusty externally. The content of graphite in clear crystalline

¹ Pumpelly and Wolff: Mon. U. S. Geol. Survey, Vol. XXIII, pp. 72, 85.

scales is nearly constant, and its amount increases with the increase in the rustiness. When not crushed it abounds in bands of blue quartz, sometimes 2 to 3 inches thick, which disappear with increasing granulation. This granulation gives a peculiar sandy look to the rock, different parallel layers of crushed quartz being now white, now rusty, as the crushed mass was influenced by the rusting of the pyrite. Small bands of impure limestone, now mostly changed to a pale-green salite-actinolite rock, appear, and the graphite is often so concentrated in them that they have been mined.

Such a bed appears in the brook crossing the road a few rods west of the overhead bridge on the railroad a mile south of Hinsdale, and, as a line of big salite-actinolite boulders, can be followed a mile farther south along the crest of the hill above the big limestone bed.

The contact on the Becket gneiss is very clear at the signal station on the apex of Warner Mountain, the highest point west of Hinsdale village, but across Washington and Becket to North Becket the Washington gneiss is much of the way wholly crushed and the blue quartz destroyed, and in many beds the content of pyrite is small. Where

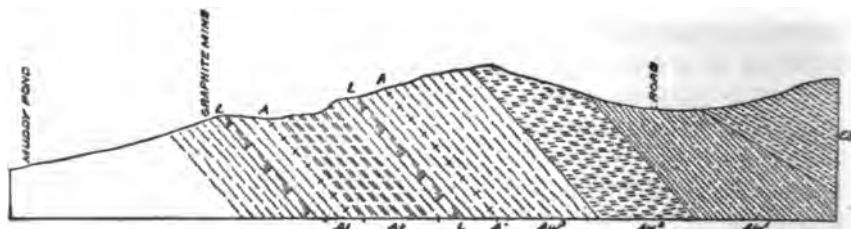


FIG. 3.—Section at lead mine east of Washington Station. Cb, white friable biotite-gneiss (Becket gneiss); Aw¹, white hornblende-spotted gneiss (Washington gneiss); Aw², granulite (garnet-gneiss); Aw³, rusty graphite-gneiss; At, stretched biotite-gneiss (Tyringham gneiss); Al, light-gray biotite-gneiss (Lee gneiss); L, limestone; A, amphibolite.

this is the case the graphite is rare, for graphite and pyrite go together. Along this line the Becket gneiss is exceptionally crystalline and coarse grained, so that it is with difficulty distinguished from the Washington gneiss. The Becket gneiss is, however, a pure biotite-gneiss carrying many large garnets, which are absent in the Washington gneiss, and it is rare that a ledge of the latter will not furnish considerable graphite. Along the east side of the area the country is covered by surficial deposits, and the last place for study is east of Washington Station, where the outcrops are abundant.

Following the road from the station a mile east, to a point where it runs north and south, north of a small pond we find the road to be the boundary between the Becket on the east and the pre-Cambrian on the west. Going over the great bare hill we have the following section ending with the lead mine and giving the whole thickness of the Washington gneiss (Pl. I, fig. 3). The great beds of white gneiss are quite exceptional and are exceedingly like the Cambrian at first view. They are, however, more feldspathic, and their scanty black constituent is mainly hornblende.

PETROGRAPHICAL DESCRIPTION—CAUSE OF THE BLUE COLOR IN THE QUARTZ.

Blue-quartz gneiss.—At Peru, near the residence of H. A. Messinger, a mile northeast of the bridge over Ashmere reservoir, there is a rusty, fine-grained gneiss (Pl. I, fig. 2), with little mica (biotite) in distant flat sheets of small scales, and with greasy blue quartz in grains and flat plates 1 to 3 millimeters thick, which often coalesce into parallel layers of considerable extent. These layers are plainly secondary infiltrations in a fine granular ground which has the aspect of a fine sandstone or quartzite, while they have much the position of the quartz blades in a graphic granite. In a plane at right angles to the dip they appear as rounded or slightly flattened ends of blades, which have their flat sides in the foliation plane and are often greatly elongated parallel to the dip. Under the microscope this ground proves to be an exceedingly fine-grained mixture of quartz, orthoclase, microcline, and abundant minute scales of muscovite; and it is such a structure as may have been produced by the crushing of granite and the change of most of its feldspar into muscovite. It is shown in three bands, of varying width, running across the slide. The darker shading in these bands represents a concentration of rust which permeates the whole layer.

The blue quartz, which crosses the slide in four bands, contains few minute broken rutile needles, rarely cavities containing small, rapidly moving bubbles, and many rudely parallel sheets of very fine cavities or grains of some unknown mineral. There are a few distant fissures. It shows strong undulose polarization, which appears in broad patches of deep shade elongated with the length of the bands and moving across them. This is indicated by the shading of the bands in the figure. The whole of each of the bands of the blue quartz polarizes as a single individual, however large it may be. The sections were cut at right angles to the foliation and about parallel with the dip or stretching of the rock. It is interesting that in each case they are cut at right angles to the optical axis, and the slide can be moved from one end to another of the blue quartz bands, 1 to 2 millimeters wide and 15 millimeters long, and the optical figure remains sharply defined, regular, and unchanged.

A fragment heated for a long time with the bellows blowpipe retained its color without perceptible change. Even in the thin section the quartz shows a rich blue, like a fluorescence, when examined by transmitted light and without a lens.

At Washington, on the north line of the road to Pittsfield, there is a coarse membranous biotite-muscovite-blue-quartz-gneiss (Pl. I, figs. 3-5). Broad continuous films or membranes of fine scales of biotite and muscovite, one of which runs through the middle of the figure (which represents a transverse section of the rock), wrap around layers or lenses, from a half inch to an inch wide, of a fine granular buff-colored mass, or around feldspar augen. This granular mass, which is shaded in the figure, is a quartz mosaic with very many regularly distributed muscovite crystals replacing most of the feldspar.

The blue quartz, in grains or flat lenses, shows a preference for a position between the membranes of mica and the fine granular ground-mass, and seems to be a late addition to a crushed biotite-gneiss. In the figure the blue quartz separates the mica film from the granular mass on both sides. It contains broad sheets of small grains and pores, with moving refractile bubbles and few cracks. It shows undulose extinction, which is represented by the soft shading upon Pl. I, fig. 3. Each band is a single crystal, at least for a long distance, and in the broad band at the bottom of the figure the slide was moved 8 mm. without any movement of the axial cross.

The most striking and instructive things about the slide are, first, that the blue quartz shows, in spite of its great thinness, an opalescent blue color almost as clear as in the hand specimen, and, second, that the blue color is absent in irregular spaces, mostly along the borders, though the quartz does not show any other distinguishing feature and is only rarely separated from the rest by a visible fissure.

In fig. 4 of the plate, which is an enlargement of the lower portion of the upper quartz band in fig. 3, the colorless portions are distinguished from the rest by being dotted and by a dotted boundary. In fig. 5 of the plate the same is drawn with crossed nicols, and it is seen that the portions which were colorless appear, in polarized light, broken into a mosaic whose grains, being relieved from tension, polarize with sharp uniformity, while the blue portions show strong undulose extinction, as is indicated by the central shading. It is thus quite evident that the blue color is due to strain, which is effective in a very thin layer, and that the strain is relieved and the color discharged by the crushing of the mass to a mosaic.

It is curious that a double series of rhombohedral cleavage lines runs through the broadly crushed portion figured and extends beyond it into the uncrushed portion without relieving the tension. The quartz is often crushed at the border and even clear into the center, but with the lens the blue color can be seen until the crushing is complete.

I first found these blue quartzes as grains in the gneissoid Upper Devonian conglomerates of the Bernardston series in West Northfield. Soon after beginning the study of the pre-Cambrian around Hinsdale I remarked the constancy of the blue quartz as a characteristic of the pre-Cambrian rocks of the region. On visiting Professor Wolff I found that he had noted the same thing and had made microscopical examinations of the rocks, and thought that the structure might be caused by strain; but he does not discuss the matter in the final report.¹

Later, on examining crystalline rock from the southern Appalachians at the Survey office in Washington, I was struck by the prevalence of the same lavender color in the quartz; and finally, in a collection of rocks from Smiths Sound, in the Arctic region, obtained by Hayes and presented to Amherst College, I found a large specimen of the finest blue-quartz gneiss I have ever seen. It is a rich deep blue, like the

¹ Geology of the Green Mountains in Massachusetts, Mon. U. S. Geol. Survey, Vol. XXIII, p. 46.

finest cordierite, and is in a layer more than an inch thick extending across a large specimen. I have observed the same thing in the Archean gneiss at Gutwagen in Norway, in porphyries in Finland, and in the granites and quartz-porphyries which extend from Marlboro, Massachusetts, to Providence, Rhode Island.

It is a peculiarity of this coloring that it is best observed with a lens, which detects immediately if it is the true color of the quartz and not a grayish blue depending upon impurities or some fine corrugation of the surface.

The foregoing facts concerning the crystalline continuity of the blue quartz layers and lenses for considerable distances, their strained appearance, and their tendency to form on one side of the mica films, or, as in the center of Pl. I, fig. 4, on both sides, make it probable that they have entered into the composition of the rock at a somewhat late stage, and have since been only partly crushed and incorporated into the general mylonitic mosaic.

An antecedent state of many of these rocks may have been a well-crushed biotite-gneiss, and it is interesting to see how diverse the crushed masses are in the preceding examples.

In one case the rock is a large-grained plagioclase mass, regularly crowded with small sharp epidotes; in another it is almost all microcline, similarly but not so abundantly filled with epidote; in another case the epidotization is carried so far that little feldspar remains; in still another the crushing has changed the larger portion of the feldspar into a mass of small, stout, muscovite crystals.

Except when the large and strongly warped cleavage faces of the feldspar appear still uncrushed, this ground has a very clastic appearance and the blue quartz seems to be connecting thin bands of a firm quartz-sandstone.

This structure in the gneiss illustrates a tendency of the quartz to undergo torsion, or bending, rather than to become granulated under a pressure which would completely crush the other constituents.

DALTON ANTICLINE.

This is a normal flat arch with the Cambrian conglomerate-gneiss worn off from the crest, exposing the upper portions of the pre-Cambrian. (See fig. 4, p. 40.) The crest of the arch runs south from Dalton along the top of Warner Mountain, the north end of which is in Dalton called Day Mountain, and near the line between Dalton and Hinsdale.

The site of the Dalton clubhouse, a mountain house on the top of the high flat hill overlooking the Dalton railroad station, 1,340 feet above sea level and three-fourths of a mile south of Dalton, is a convenient landmark by which to find this most interesting contact of the conglomerate upon the older gneisses.¹ The clubhouse, locally called

¹ For description of the conglomerate contact see page 75.

"the Chalet," is now removed, but the foundations still remain, and the road can be followed from the station, the clearing making a notch in the woods at the top of the mountain visible from Dalton.

The pre-Cambrian, at the contact a few rods southeast of the clubhouse, is a fine-grained crushed granulitic gneiss, but abundant beds of the rusty blue-quartz gneiss come in just east of this. Farther south the blue quartz is everywhere abundant.

Along the boundary, going southwest to the brook which runs through the pasture south of the clubhouse, allanite is an exceedingly abundant accessory in the gneiss, a dozen crystals often appearing in a single hand specimen. It is especially abundant near a large tree at the middle outcrop of the brook bed, indicated in the figure.

A little farther up the brook bed is a very peculiar granular quartz rock containing considerable feldspar and calcite in large, rounded balls, often 3 to 4 inches across, which consist of one or a few crystals



FIG. 4.—Dalton anticline: The Dalton clubhouse section on Day Mountain south of Dalton. Cambrian conglomerate-gneisses arch over the pre-Cambrian unconformably.

and show very large cleavage surfaces, presenting the finest twin striation. These balls are sometimes blended into masses of very coarse marble as large as a man's head. There is much pyrrhotite developed, especially along the borders between calcite and quartzite, and biotite also occurs in the calcite.

At the south end of the mountain ridge the pre-Cambrian terminates in a fine bluff overlooking the Warner Mountain or South Dalton fault. At the southwest corner it dips under well-marked Cambrian conglomerate-gneiss and shows heavy hornblende-gneiss beds in graphitic blue-quartz gneiss. The southeast corner is three-fourths of a mile N. 20° W. of the signal house on the top of Warner Mountain, and the sudden ending of the blue quartz gneiss against the fault is clearly exposed.

The schist upthrusts in the Stockbridge limestones, which are prominent farther north and disappear in the latitude of Pittsfield, opposite the Dalton anticline, the lesser folding of these limestones compensating for the Dalton anticline.

COLES BROOK LIMESTONE.

A remarkable linear outcrop of the Hinsdale limestone 7 miles long, has cut through the Cambrian gneisses like a knife, from Factory Hollow, in Middlefield, to the south part of Becket. It is bounded everywhere by faults, is accompanied by only narrow selvages of the pre-Cambrian gneisses, and, unlike all the other outcrops of the limestone, forms a series of high, steep ridges. It is best exposed a mile north-west of Bancroft Station, in Middlefield, where the Boston and Albany Railroad cuts off a loop of the Westfield River and Coles Brook enters this loop from the north. The Cambrian gneiss overlaps the pre-Cambrian unconformably on either side.¹

The white Cambrian conglomerate-gneiss in synclinal posture mounts unconformably on the older Lee gneiss, which consists of a great thickness of a wavy bedded gneiss of fine grain and almost black from the abundance of black biotite.

The Lee gneiss abuts, apparently by a fault, certainly by a wholly abrupt transition, upon a band of the coarse, white, almost micaless Hinsdale gneiss, with iridescent feldspar, which is 23 feet wide below but narrows above.

This is followed by a bed of white, thin-bedded, highly crystalline limestone 50 feet wide, with thin films of serpentine, which is separated, by 108 feet of the same dark Lee gneiss, from a second band of similar limestone, of which only 29½ feet are exposed. The partial serpentinization of the chondrodite has here produced a yellowish verdantique which furnishes very beautiful hand specimens and might be useful for ornamental work.

Following this, in the brook bed at bridge 142 and in the railroad cut, is a large mass of the dark gneiss-carrying beds of hornblende-schists, until we come to the fourth telegraph pole from bridge 142, upon the fine unconformity where the conglomerate-gneisses mount the dark pre-Cambrian gneiss.

Between this point and Middlefield Station the cuttings expose a long extent of contorted and twisted rocks, mostly of Cambrian age, the beds swinging round from horizontal to vertical within a few feet.

Gradually a low dip eastward predominates, which becomes steeper, and a band of hornblende-gneiss 10



¹ The whole section is figured and described by the author in Mon. U. S. Geol. Survey, Vol. XXIX, pp. 21-24.

feet wide sets in, while at the signal house a boss of coarse Hinsdale gneiss and calcareous salite-actinolite-schist protrudes. East of the unconformity all is Becket gneiss, except the few hornblende-gneiss masses and the last-mentioned boss of Hinsdale gneiss, which are brought just above the railroad level by the undulations of the Becket gneiss.

The limestone can be followed a considerable distance north along the brook, and it gradually passes to the east bank. Its most northern outcrops are south of the schoolhouse at Factory Village, in Middlefield, and the long depression, occupied by the pond, which extends north from this point has been formed by its solution. To the west are heavy hornblende-gneiss beds (Lee gneiss).

South from Coles Brook the limestone rises in a great hill south of the Middlefield railroad station, where it is 330 feet thick and is inclosed in a fine granulite.

Westward, toward Becket Center, a ragged, castle-like ledge of calcareous actinolite-gneiss, much contorted, forms the bare crest of the hill south of the road, and just east of this ledge is a bed, 75 feet thick, of a

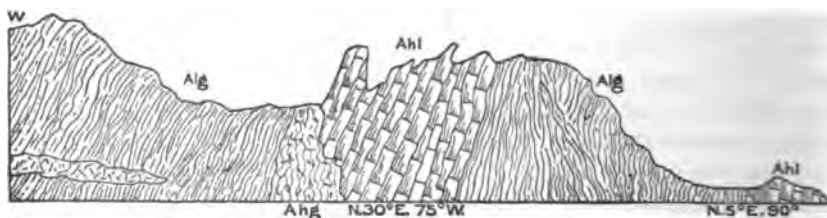


FIG. 6.—The Coles Brook limestone, enlarged from fig. 5.

coarse, well-bedded chondroditic limestone standing vertically. It is full of nodules, often 15 inches across, consisting of salite, tremolite, titanite, and chondrodite. Other nodules are wholly of pale-green bladed tremolite. On the south of this hill the limestone is exposed with a thickness of 250 feet, and farther south, where it crosses the road (at the house of Ellsworth and son), it is 660 feet wide. Where it crosses Walker Brook and the last road on the quadrangle, the limestone is exposed to a thickness of 100 feet, and can be followed south across a blind road, turning south from the main road to a house known locally as "the old Conn place." Just south of this house great masses of the blue-quartz graphite-gneiss accompany the limestone, which can be traced but a little way farther south, as the Becket gneiss closes in on it.

The limestones of this locality are first noted by President Hitchcock in his final report¹ as occurring in the west part of Middlefield on Pontoon turnpike, on the railroad at the mouth of Coles Brook, and 1 mile east, in the southeastern part of Becket. The first two localities are on the Coles Brook bed; the third was a line of great boulders from this bed. The description of the Hinsdale Station limestones

¹ 1841, pp. 81, 85, and 567.

given on pages 27-28 will apply wholly to those of this locality, and the change of chondrodite into serpentine may be better followed here. The former rock is, however, coarser, and the included minerals are in larger individuals and therefore better fitted for mineralogical study.

LIMESTONE ON THE ALDERMAN FARM IN BECKET.

A mile east of Center Pond, in Becket, a thick bed of pre-Cambrian limestone has been opened. It has a width of 82 feet, and is a coarse chondrodite-phlogopite marble.

At its eastern contact is a selvage, 4 feet wide, of pale-green or partly olive-green actinolite-pyroxene rock, which consists for the most part of a loose network of coarse actinolite blades, with some large masses of pale-green pyroxene and pyrite. It contains amethyst, much titanite in the usual flat crystals, and orthoclase

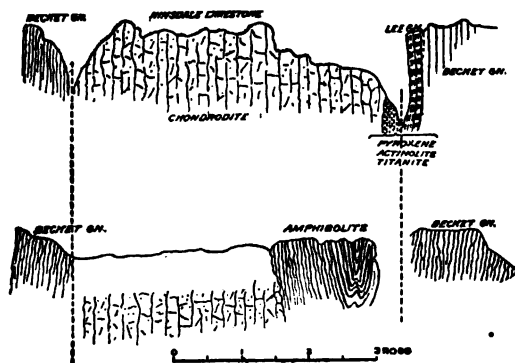


FIG. 7.—Hinsdale limestone at Alderman quarry, Becket. Lower section 10 rods south of upper one.

in small well-formed crystals with simple forms, rounded edges, and blue opalescence. The bed is bordered on the east by 3 to 4 feet of a dark-banded gneiss of the type of the Lee gneiss, and the whole is inclosed in the Becket gneiss. About 8 rods south (see lower section of fig. 7), in the line of the strike, appears a great bed of a black hornblende-schist, which rests against the vertical Becket gneiss on the east, while the same gneiss appears in its proper place on the west, the intervening space being low covered ground. This hornblende-schist seems clearly to be the continuation of the limestone. It was prospected quite extensively, first for copper and then for emery. A study of thin sections showed it to be a hornblende-biotite-garnet-gneiss, with little black ore and much leucoxene and plagioclase.

GULF ANTICLINE, DALTON.

North and northwest of Dalton the country rock seems to be entirely the massive quartzite, but going north by the second wood road, after passing the highest point on the "Gulf road," 30 rods from the highway, one finds outcrops of the gray Becket gneiss. Twenty-five rods above is the coarse, flesh-colored, pre-Cambrian biotite-gneiss, with blue quartz. This can be followed a long way up the brook, to the point where the main wood road crosses the brook, near an old cellar and 80 rods from the "Gulf road." The pre-Cambrian here extends west beyond the woods into the open pasture, and continues in that direction

across 40 rods of Becket gneiss, to the long, bare ridge of quartzite which overlooks the railroad on the west. It can be followed still farther north, to its apex on the high, bare hill, at an altitude of 1,720 feet. Here is a broad, bare hilltop of the Becket gneiss, and at the southwest portion of the flat is the northern apex of the pre-Cambrian—a green, calcareous, highly feldspathic gneiss carrying dark-green fibrous hornblende, titanite, and blue quartz. The Becket gneiss wraps around it, and the contact is perfectly exposed. The Becket gneiss is conglomeratic at the south. A band of Becket gneiss about 40 rods wide surrounds the entire pre-Cambrian area, and the quartzite surrounds the whole. The axis of the anticline runs northeast, and the dips are all southeast, the anticline being overturned to the west. Mr. Benjamin Newell sent me specimens of the fresh rock from a point about 2 miles northeast of Dalton, and a specimen of coarse feldspathic pre-Cambrian gneiss, full of half-inch spots of a biotite-garnet aggregate. This is directly on the line of the axis of the gulf area of pre-Cambrian described above, and indicates a small pre-Cambrian area on the south border of the Greylock quadrangle.

LEE-TYRINGHAM AREA.

DISTRIBUTION.

This is the largest pre-Cambrian territory in western Massachusetts. It begins in a lobe overlooking Sackett Brook, in the south part of

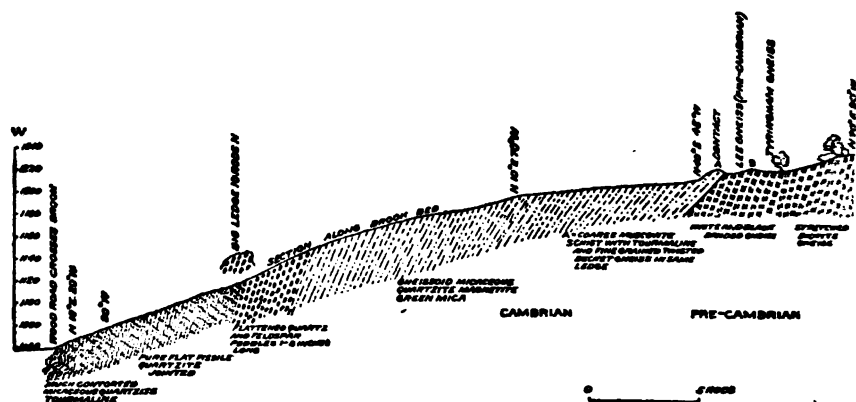


FIG. 8.—Section of contact of Cambrian on pre-Cambrian east of Lenox Furnace.

Dalton, where it is a slightly overturned anticline. It expands between Ashley Brook and Roaring Brook as a normal anticline, with axis running north and south. This is connected by a narrow isthmus with the larger and more important area, which begins on a fault in the high ground southwest of New Lenox, expands rapidly across Washington, occupies all the high ground in Lee and Tyringham, and ends in the great mass of Kingsbury Mountain, against the Tyringham fault.

It is convenient to treat separately the further extension south of this fault as the Sandisfield area (see page 55).

BOUNDARY.

The eastern boundary of this area is nearly everywhere normal, being formed by the Cambrian gneisses, which are often conglomeratic. It extends southeastward across Washington, with several great lobes running northward to a point south of Becket Center, where it turns southwestward, becomes an unconformable boundary, and, crossing into Otis, east of where the Tyringham River enters the town, extends southwestward to West Otis, where it meets the Tyringham fault.

Between New Lenox and East Lee the western boundary runs at the foot of the bluff overlooking the Housatonic Valley, and is a line of fault, with downthrow on the west and some westward overthrust. (See figs. 8 and 9.) Along this line the western half of the Lee-Tyringham pre-Cambrian dome is absent, and the Cambrian white gneiss and the lower part of the quartzite are carried down and concealed, the different beds of the pre-Cambrian on the east coming successively into contact with the quartzite on the west. (See Pl. VII, p. 86, and section D E.) East of East Lee the fault bends sharply, influenced by the northward thrust of the country to the south, and in the hill south of East Lee the boundary changes from an overturned and faulted contact to a normal contact, the Cambrian gneiss mounting unconformably over the pre-Cambrian gneisses.

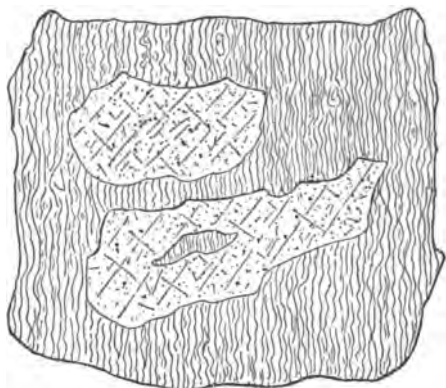


FIG. 9.—Layer of Cambrian slate on vertical Lee gneiss (at B, fig. 8), Lenox Furnace.

STRUCTURE.

Greenwater Pond anticline.—Along its northeastern border the Washington gneiss includes a wide band of Becket gneiss in a normal syncline which extends across Washington and Becket. West of this the Tyringham gneiss crops out over a broad area of great monotony. Still farther west is the curved axis of the important anticline of Greenwater Pond.

Limestones lie along the bottom of the deep valley. The steep walls are composed of the heavy black Lee gneiss, above which the barren Tyringham gneiss extends in low undulations a long way north and south, and finally sinks below the Washington blue-quartz gneiss. The axis of the Greenwater Pond anticline is continued beyond Shaw Pond and ends in the middle of the area, where it is covered by the unconformable Cambrian gneisses.

East Lee anticline.—A mile east by south of East Lee another small but very interesting anticline, with eastward pitch, exposes the limestone bordered by the Lee gneiss.

Goose Pond anticline.—A mile farther on, Goose Pond lies in the bottom of a curved anticline, with axis pitching south and east at either end, which also exposes the pyroxenic limestones.

The deep valley in which lie Goose Pond, Long Pond, and its tributary brook has been formed by solution of the limestone. It overflowed for a long time into the Tyringham Valley, wearing a deep trench down the mountain side. This valley seems to have been tapped by the wearing back, along the axis, of the East Lee anticline.

The Goose Pond anticline is symmetrical with the Lee-Becket anticline in its Long Pond portion, and bends around in sympathy with the East Lee and Tyringham anticlines in its western portion. It has thus a curved shape like the Bear Mountain anticline (see p. 58).

The axes of these folds end abruptly on the west against the important fault that runs at the foot of the bluff from New Lenox to East Lee, which may be called the Lenox fault. The western prolongation of each of these anticlines was thus dropped below the level of the sea, in Cambrian times, and covered by the Cheshire quartzite and the Stockbridge limestone.

Foxden anticline.—The next interruption to the expanse of the Tyringham gneiss is a broad anticline of the banded Lee gneisses, which begins a mile and a half east of the outlet of Goose Pond, crosses the next road south, with a width of nearly a half mile, and ends unconformably a mile south of this road at a large ruined house, locally called Foxden, overlooking the Tyringham Valley.

The exposures here show perfectly the anticlinal position of the white-and-black banded gneisses in the stretched Tyringham gneiss, and the unconformable overlap of the white Becket gneiss upon the denuded anticline. Only a trace of limestone was found in the core of this anticline.

Hop Brook anticline.—The last interruption to the Tyringham gneiss before reaching the Tyringham fault is the Hop Brook anticline, at the foot of the Tyringham Valley. It is very interesting, both because of the abundance of fine minerals from the limestones of its core which have been found by Mr. Daniel Clark, of Tyringham, and from the light it throws upon the blocking out of the pre-Cambrian valley, into which the deep waters of the Cambro-Silurian sea penetrated, for the deposition of the calcareous beds now altered to the Stockbridge marble.

At the mouth of Hayes Pond, southeast of the valley, is a bed of green pyroxene-actinolite rock 40 feet wide, which, with the associated gneiss, represents the east end of the core of a long, narrow limestone anticline. The white-and-black banded gneisses wrap round the core and pitch steeply east, and can be followed across the pond and up the hill a half mile northwest, where they run under the Cambrian gneiss. They can be seen bending around from a south to a west strike at the house a little way south of the pond, and thence extend west to the

Tyringham fault. The last green actinolite beds of the core are near this house, and the deep erosion of Hop Brook has exposed the core, with many impure limestone beds, still farther west, to a point about 20 rods from the small settlement called Sodom, in Tyringham. They here go under the Cambrian gneiss, reappearing 4 miles down the valley at the Brookside mill, in the village of Tyringham, where, below the dam, the impure pre-Cambrian limestone, with chondrodite, wernerite, and titanite, appears beneath a low arch of Cambrian tourmaline-bearing gneiss, and is continued westward in a small isolated area of blue-quartz gneiss, which is exposed along the road running west down the Tyringham Valley from the mill to the town line. On the hillside above is a thin veneering of Becket gneiss, which has been worn off in the bottom of the valley. Blue quartz occurs in the striking cliffs by the roadside near the town line.

GENERAL PETROGRAPHICAL DISTINCTIONS.

Beneath the white Cambrian gneisses which border the area the Washington blue-quartz gneiss appears everywhere. Below this is a coarse biotite-gneiss, which is quite uniformly free from all accessory minerals and from beds of any different rock type. It is so highly stretched that it shows a ligniform, or small columnar, rather than a common foliated structure. I have called it the Tyringham gneiss.

It rests on a thick bed consisting of well-banded alternations of white granular gneiss and heavy black hornblende-gneiss or hornblende-biotite-gneiss, which I have called the Lee gneiss, and this rests upon the impure limestones which appear in the core of the anticlines.

The Lee gneiss is practically a calcareous facies of the gneiss in the neighborhood of the heavy limestone beds, and it sometimes seems to pass laterally into the Tyringham gneiss.

Hinsdale gneiss.—This rock is absent in the Sandisfield area, as the limestone is nowhere cut through to show the rocks which underlie it. On the road from Lenox Furnace to Washington occur boulders of a coarse, zircon-bearing biotite-gneiss which closely resembles it but which could not be found in place.

Hinsdale limestone.—The fact, first suggested by Professor Dana,¹ that the removal of the limestone has formed many of the lake basins and valleys in this beautiful lake region, is of great value in the study of the distribution of this rock. The two valleys at East Lee, and the continuation of the more northern across the low col into the Farmington River Valley, Goose Pond, and several ponds in Sandisfield, are illustrations.

Observation is difficult, as the rock is covered by drift and water in bottoms of the valleys and must be studied mostly in boulders. It is never exposed in beds so great as those in the Hinsdale area and is never so pure as there.

¹The South Lee, the Hinsdale, and the Tyringham valleys are instanced as showing the influence on the outline of the Stockbridge limestone areas exerted by preexisting Archean channels or bays. J. D. Dana, *Am. Jour. Sci.*, Vol. XXXIII, p. 276.

It is a coarse-grained, greatly gnarled and twisted rock, deeply weathered in the great bowlders which cover the surface where it occurs. It contains pyroxene and hornblende varying in color from deep green to white, phlogopite, muscovite, biotite, chondrodite, wernerite, titanite, chloritoid, orthoclase, graphite, quartz, pyrite, and pyrrhotite.

Several of these minerals are always present in large amount, in varied and often quite characteristic groupings in different parts of the area. For instance, chondrodite is found most abundantly in masses larger than the two fists on the hill southeast of East Lee, wernerite north of Otis and in the bottom of the Tyringham Valley, and titanite in the northeast corner of Sandisfield, etc.

One mineral common in similar limestones is absent in this region. This is spinel, which is, however, found just south of this district, in Norfolk, Connecticut.

Lee black gneiss.—In the bluffs which border the East Lee Valley on the north and its continuation across Becket occur thick beds of a black, very heavy hornblende-magnetite-biotite-gneiss, which occupies a very constant position above the Hinsdale limestone and becomes a horizon of great value.

It represents a calcareous transition band above the limestone. A thin bed of a rusty graphite-pyrite quartzite seems to separate it from the limestone on both flanks of the East Lee Valley, but could not be found in place.

Along the south side of the valley and on both sides of the next valley to the south, by which runs the road to Goose Pond, the rock is still more strongly magnetitic, so that it is often prospected for iron, especially on the high hill a mile southeast of East Lee. It also abounds in large iron garnets, and this peculiarity can be traced along the north side of the East Lee Valley into Becket. Along both sides an upper bed is leek green and pyroxenic.

This rock also appears in considerable force in the crest of the high ridge north of East Lee, and may be studied by going up the hill road, starting 30 rods east of the East Lee Hotel. At the 1,400-foot contour the woods begin, and at the northwest corner of the clearing are two apparent ledges, which I assigned to the Becket gneiss but found to be great bowlders of the same. From this point a wood road runs up over the black hornblende gneiss for 30 rods, and the rock ends where this road emerges in a clearing on the crest of a hill. Here it is a black, medium-grained rock, thin splitting and flat bedded. It is an anorthite-amphibolite, and a thin section (No. VI, 131a, National Museum Collection) of the black foliated rock cut transversely showed only a trace of quartz, little partly bleached biotite and magnetite, and no titanite. The green, moderately dichroic hornblende is not fibrous, but is in stout, ragged blades appearing in all directions in the slide. The centers of the blades contain many impurities.

The pleochroism is: a = yellow, b = yellow-green, c = blue.

The mosaic of anorthite occupies half the surface; about half shows multiple twinning with large angle of extinction; half the remainder shows concentric extinction, but no twinning. It incloses much hornblende in small plates and in minute straight needles.

The feldspars have very generally a common orientation, so that in the field they show a positive obtuse axis eccentric, with the axial plane about parallel to the twin striation.

There was nothing in the section that would lead one to think it an eruptive, and all its associations connect it with the calcareous gneisses.

A little west of the wood road before mentioned, the rock is white-and-black banded and is greatly twisted in its bedding. Farther west the quantity of hornblende diminishes, and north of the before-mentioned Becket gneiss boulders it disappears and the rock graduates, with the strike, into the stretched Tyringham gneiss. It can be followed east as far as the limestone ledge, and here also it becomes a light-colored slightly hornblendic gneiss.

It is subordinate to the Tyringham gneiss, but as it borders the limestone areas in the different valleys for so long a distance it seemed well to maintain its distinctness within the area.

Where the band crosses the blind road on the mountain, a mile farther east, at the point where this road runs most northerly, it is a ribbon gneiss of many small hornblende bands interleaved with white gneiss bands.

On the southern side of the valley it can be best studied in the hill south of the hotel in East Lee, and is described in connection with the Hinsdale limestone. (See p. 33.)

It is well exposed along the desolate road which runs from Tyringham Valley over the mountain to West Becket as a series of markedly flat-bedded gneisses, of fine grain, which for nearly a mile across their strike present a continuous alternation of black and white beds from a fraction of an inch to 12 feet in thickness. The white beds have the appearance of quartzite, but are a compact quartz-feldspar mixture which looks as if it had been thoroughly crushed and recemented. The black layers are black from the great quantity of biotite and hornblende, and some beds are a heavy, black granular hornblende rock which resembles crushed tourmaline.

Tyringham ligniform gneiss.—This gneiss is, in perfect development, composed of bundles of quartz-feldspar pencils wrapped round with biotite. The dip is easily obtained but the strike often with difficulty. The rock is best developed across the center of Tyringham on both sides of Goose Pond. It is a coarse biotite-gneiss of very uniform character, barren of all accessories. Its biotite is gathered in elongate films more or less wrapped round the other constituents, and is generally rather dull black. The rock is very prone to decomposition.

Washington blue-quartz gneiss.—The peculiar lavender quartz so char-

acteristic of the pre-Cambrian in the Appalachians is found in all the members except the limestone, but in the upper horizon it becomes extremely abundant and characteristic, so that it is the most constant guide to the settlement of the boundary between pre-Cambrian and Cambrian.

The rock is a coarse biotite- or biotite-muscovite-gneiss. Pyrite is a uniform and often abundant constituent, and the rock is always rusty. Graphite, so uniformly abundant and characteristic of the rock in the Hinsdale area, is found in quantities only part of the way across Washington, but reappears much farther south, in Sandisfield and New Marlboro.

Allanite, which is also abundant in Hinsdale, appears frequently in Becket and Tyringham.

The blue quartz appears in scattered nodular masses, often nearly an inch thick and fusing together into films on the foliation plane, and when the rock contains also large garnets and allanite, with the peculiar puckering around the crystals, it is beautiful and striking. The quartz is often granulated by crushing till only a small center remains, and the color is then wholly discharged. This crushing into a white sugary sand is very characteristic of the rock.

Where it crosses the road north of Ashley Brook it is a very coarse granite-gneiss, like that of Hoosac Mountain. The feldspars are often 4 inches across, at times resembling pebbles and having broad, curved cleavage faces. The blue quartz bands are sometimes 2 inches thick. Other beds are crushed to a fine granulitic rock, with flat, elongate, blue quartz seams.

The gradual granulation, by crushing, of the blue-quartz grains and bands, accompanied by an apparent discharge of the blue color, is very clearly exhibited here in all its stages.

The gneiss along the road from the outlet of Ashley Lake to New Lenox is a coarse to very coarse, granitoid, highly feldspathic, blue-quartz gneiss. Many layers are full of large manganesian garnets, often an inch across. The biotite is in distant membranes, branching out into masses an inch across. It winds in and out among feldspar or feldspar-quartz nodules 1 to 4 inches across. There is often much coarse tourmaline.

LIMESTONE AREAS.

East Lee limestone.—The deep valley which starts at East Lee and runs in a great curve southwest to Otis, containing Greenwater and Shaw ponds, is underlain by Hinsdale limestone and owes its position and shape mainly to the solution and removal of the same.

It is deeply covered by drift, which fills the valley, and can be best studied upon the high, bare hill between the two roads running east from East Lee. It is a coarse, white, highly crystalline limestone, coarser and of more translucent grain than the adjacent Stockbridge limestone, very impure, and coarsely warty upon the surface, from the solution of the purer parts.

It contains actinolite, pale-green and black pyroxene, phlogopite, and, most important, chondrodite, and in the hill above mentioned this mineral occurs in granular masses of the pure substance as large as one's fist and in rude crystals an inch long. Wernerite does not appear in this band, as it is not common in the limestone except near faults.

The mouth of the valley is greatly clogged by thick drift deposits, in which immenselimestone bowlders are common, and by later post-Glacial sands, so that the relations of the Hinsdale limestones to the Cambrian deposits to the west can not be determined.

The most westerly outcrop of the Hinsdale limestone is the great mass on the south side of the brook just east of the hotel. This is not certainly in place, but the great size of the outcrop and the direction of the glacial movements make it probable that it is in place here or still farther west.

Thirty rods farther west is an occurrence of the limestone in the foundation of a dam. Under the building and near the water wheel it is associated with great masses of the Stockbridge limestone, and this is probably the locality cited by Professor Dana¹ as a place where the two limestones could be seen in contact.

As the Stockbridge limestones dip in three different ways, they are probably bowlders, and from the outcrops to the west it is more probable that the Cheshire quartzite intervenes across the valley mouth, separating the two limestones from each other, as is represented upon the map.

Thirty rods east of the hotel a road runs north onto the mountain, and beyond the single house by the field road leading to the top of the clearing many outcrops appear in the wall at about the 1,400-foot contour. Above the northeastern corner of the east field is a cliff with a fine spring at its foot. For several feet from the base of the cliff the rock is the warty, impure limestone carrying chondrodite and green actinolite. It grades above into zigzagged strata of white, coarse, micaless, granitoid gneiss containing layers and wisps of green actinolite. These beds are together about 15 feet thick and grade upward into a fine-grained, flat-bedded gneiss much like the Cambrian gneiss. It is the transition to the Lee gneiss.

The great bowlders of the coarse limestone are very abundant for 2 miles up the East Lee Valley, to the point where the brook crosses the road to run north, but outcrops rarely appear.

The presence of these bowlders, the continuance of the bordering Lee gneiss in the hillside north and south, and the deep, continuous valley form the ground for believing that the limestone continues along the bottom of the valley.

Goose Pond limestone.—The limestone is almost wholly buried beneath the waters of the ponds, and the barren, stretched Tyringham gneiss appears in the heavily wooded and till-covered banks. In several

¹ On Taconic Rocks and Stratigraphy: Am. Jour. Sci., 3d series, Vol. XXIX, 1885, p. 205.

places the coarse chondrodite-limestones and the coarse pyroxene rock which replaces them form the shore, notably at Elwells Rocks, on the south side of Long Pond toward its eastern end. The superjacent hornblendic Lee gneisses appear in force at the end of the blind road south of Greenwater Pond.

Hop Brook limestone.—Starting 20 rods above the dam, at the small village of Sodom at the head of the Tyringham Valley, the bottom and steep banks of the brook show ledges and large bowlders of a coarse limestone which is more often a coarse-grained aggregate of silicates, both anhydrous and hydrous. Around the village of Sodom itself and at the foot of the steep cliffs farther east many large blocks of the same rock appear, which seem to have been brought down by the torrents of the brook, as they lie far north of the pre-Cambrian outcrops in a direction opposite to the trend of the ice in this region.

At the entrance to the road that leads to Sodom stands the house of Mr. Daniel Clark, whose splendid collection of minerals from the valley and large store of knowledge of the mineralogy of the country will be placed at the service of any student.

The outcrops are mostly concealed in the steep, moss-covered banks of the mountain brook, and they have been exploited at much expense by Mr. Clark. I spent several days studying his collections, and the special peculiarities of the minerals which occur here are described in the mineral lexicon appended (pp. 103-127).

The masses of white, granular quartz-calcite mixture, with small amount of green pyroxene, titanite, and tourmaline from the altered limestone, are catalogued by President Hitchcock as "augitic gneiss from Lee and Washington," in catalogue of Massachusetts collection, under gneiss, 92 to 95.¹

"Mortised rock" of Tyringham.—At Tyringham quartz pseudomorph after plagioclase is found, penetrated by square cavities from which salite has been removed. (See Pls. II, III.) In these most remarkable specimens great masses of clear vein quartz are penetrated by square cavities from which large crystals of salite have been dissolved, while the quartz proves to be pseudomorph after large masses of plagioclase, presumably albite.

The replacement is so delicately perfect that the twin structure is perfectly preserved, exactly as in cleavage surfaces of albite. This twin striation appears over large areas and is absent over other large areas, and the alternation occurs both in the direction of and at right angles to the striation.

Moreover, the pearly luster of the 0 (001) face is perfectly reproduced in the fractured surface of the quartz, showing that the replacement has preserved the structure of the albite, on which the pearly luster depends; that is, repeated separation along the cleavage planes and

¹ Rept. of Mass. Board of Agric., Appendix, 1858, p. 51.



MORTISED ROCK; QUARTZ PSEUDOMORPH AFTER ALBITE, CONTAINING CAVITIES OF
SALITE CRYSTALS; TYRINGHAM.



MORTISED ROCK; QUARTZ PSEUDOMORPH AFTER ALBITE, SHOWING TWIN STRIATION AND PEARLY LUSTER, WITH CAVITIES FROM WHICH SALITE CRYSTALS HAVE BEEN REMOVED; TYRINGHAM.

the formation of air-filled interspaces which have the effect of Newton's rings.

Many of the quartz fragments split into large, acute, wedge-shaped pieces, which are aggregated in alternate arrangement of the separate wedges exactly like the Clevelandite variety of albite from the tourmaline-pegmatite veins.

The Tyringham specimens present an interesting and complete series, showing the alteration and disappearance of the pyroxene. There are, first, masses in which the long, white, four-sided prisms of salite, sometimes slightly truncated at the edge and distinctly striated on some faces, are from a half to a quarter inch in thickness and several inches long, loosely aggregated, and passing into a compact salite rock.

There are other specimens in which the same white prisms are inclosed in white or smoky quartz. They show the very strong basal parting of salite, and are often an inch across. They can be seen to be in some places wholly or partly replaced by a secondary tremolite or pale-green actinolite, and the quartz shows distinct traces of the tabular form and the twin striation of albite.

In other specimens the whole or almost the whole of the salite is dissolved, and the cavities take sharp casts of the longitudinal striation of the crystals as well as of the transverse partings which cross the cavity with the proper obliquity of the basal section of salite.

These specimens were found at Sodom, in the upper end of the Tyringham Valley, in the pre-Cambrian limestone. I was therefore greatly surprised to receive from a student a large specimen of the same cavernous quartz, which was found by his father, Mr. Charles T. Barker, during the digging of the cellar under the Berkshire Life Insurance Building in Pittsfield. It is a wholly unworn block 6 inches on a side. The angular faces look as if they might have been broken artificially, and the weathered surface of the block suggested that it had been buried many years. It is full of cavities, some of which are an inch across and 6 inches long. A 6-inch surface shows over half its area a fine representation of the albite cleavage, and half the rest has the appearance of the pearly feldspar cleavage; yet the whole is a clear, translucent quartz, from colorless to smoky, and splinters broken off from the surface showing striation displayed the perfect optical figure of quartz very obliquely placed. I can not imagine that the specimen was brought to its present place by ice, for the proof of its pre-Cambrian origin is quite complete and there is no pre-Cambrian limestone area to the northwest.

From the interest which these mortised stones have created in the past I imagine that the specimen may have come from the Tyringham Valley and have been at some time a part of a collection in Pittsfield, as the place where it was found adjoins the former habitation of the Berkshire Historical Society. This is the specimen figured in Pl. III. Mr. Daniel Clark, who has collected most of the specimens upon which the fore-

going description was based, has written me as follows concerning the Pittsfield specimen:

The specimens have never been found except as drift. I have never seen any ledge, but they occur in numerous specimens from small size to several tons. They could not have drifted far, for they were angular and showed no signs of erosion, and were found on a few acres in Sodom.

The specimen which Mr. Barker found in Pittsfield I believe to be from this locality. Over forty years ago Mr. Stephen Reed, of Pittsfield, who was interested in minerals, visited my place, and I gave him several specimens of what we then called mortised rock, and I believe your specimen from Pittsfield is one of those Mr. Reed carried from here at that time. I have never known of any specimens being found in Berkshire County except in this locality.

Metamorphosis of the pre-Cambrian limestone and paragenesis of the limestone minerals.—The following tabular statement, derived from study of the Hop Brook and Otis limestones, may make clear the probable steps by which the rich mineral beds along Hop Brook have been formed. That this has been along a line of faulting has had much to do with the complexity of the result. A detailed description of all the minerals mentioned is given later:

First stage: A fragmental limestone.

Result of vital forces and transportation. The bed was at first presumably an accumulation of animal remains First calcite

Second stage: A crystalline limestone.

Result of circulating carbonated waters with heat and pressure. In its least-changed state the bed is now always highly crystalline—has recrystallized many times in every part Second calcite

Third stage:

(a) East Lee facies. Chondrodite-phlogopite-limestone, with much clinochlore, coccolite, and graphite.

Result of circulation of heated waters carrying silica and fluorine. Characterized by very basic magnesian fluosilicates.

(b) Otis facies. Pyroxene-wernerite-titanite limestone.

Result of more intense dynamic and thermal activity along fault planes and the circulation through the limestone of heated waters containing fluorine, chlorine, and titanium compounds.

Characterized by graphite, green and white pyroxene, stout black hornblende, great blocks of wernerite and chalcedony, opalescent orthoclase (loxoclase), albite in great masses inclosing salite and calcite, and pink, white, and gray calcite in coarse crystals Third calcite

(c) New Marlboro-Norfolk facies. A limestone containing the minerals of *b* with wernerite replaced by spinel and nickeliferous pyrrhotite.

Characterized by abundant aluminous silicates, which may perhaps be derived from clayey limestones, while the chlorine may come from the ancient sea in which the sediments gathered, and the graphite from the organic remains. The abundant titanite was probably brought into the limestone from without, and this makes it possible that the same may be true of the alumina silicates.

Fourth stage: The mortised rock (*a*).

Extensive pseudomorphic replacement of albite by quartz (see Pls. II, III) without affecting the inclosed salite; resorption of salite for the formation of actinolite, which incrusts the remnant of the salite.

Result of continued action of silica solutions under changing conditions of heat and pressure.

Fifth stage: Quartz inclosing actinolite.

Extensive development of large biotite crystals in veins in which the crystals are greatly crumpled by later movements on the fault. Result of silica solutions at lower temperature.

Sixth stage: Zeolitization.

Formation of scolecite by the decomposition of wernerite. The formation of actinolite continues.

Seventh stage: Zeolitization, continued.

Development on the earlier scolecite of heulandite, stilbite, scolecite, laumontite, and calcite. Formation of jasper inclosing fragments of earlier silicates. Result of warm waters and long time..... Fourth calcite

Eighth stage: Decomposition and hydration.

Jefferisite from biotite, kaolin from feldspar; solution of calcite and etching of crystal faces. Formation of chalcedony inclosing jasper. Effect of atmospheric waters and moderate temperature.

SANDISFIELD AREA.

The long and peculiarly shaped area of pre-Cambrian rocks lying south of the Otis area and the extension of the Tyringham fault down the valley of Clam River and across Sandisfield and Colebrook, is composed almost wholly of the upper member of the series—the Washington gneiss.

In the center of the southern lobe only, where it is widest, is there a trace of the green pyroxene-hornblende rocks, usually associated with the Hinsdale limestone. The most striking occurrence within the area defined above is found at the northwest corner, in the pasture opposite the house of the mineralogist, Mr. D. Clark, at the head of the Tyringham Valley. In the western part of the pasture the white Cambrian gneiss abuts unconformably against the pre-Cambrian gneiss. The blue-quartz gneiss near the house is so full of allanite and its decomposition products that often a dozen crystals appear in a single hand specimen. In tracing these gneisses down from the north this has been found to be characteristic for a long distance. Allanite does not appear much farther south, but is replaced by fibrolite.

Along the west boundary, 2 miles south of Mr. D. Clark's, at a point a mile west of West Otis, just where the boundary line cuts the line of long. $73^{\circ} 10'$, is a beautiful unconformable contact of the Becket gneiss on heavy beds of chondrodite-clinochlore-limestone, which is very pyroxenic and has a broad border of green pyroxenite. It is a medium-grained white marble, banded in places by black ore, and occurs in sufficient quantity to suggest a possible quarry stone.

The hill $1\frac{1}{2}$ miles south by west of Sandisfield, which forms the apex of the pre-Cambrian lobe extending northwest from South Sandisfield, presents peculiar conditions. In the hollow of the north foot of the hill (south of the road) is a typical Cambrian quartzite, at first massive, then, three rods south, banded granular, with magnetite grains, which further south grades into typical Becket gneiss. Two or three rods south of this, in the north foot of the hill, is a 6-foot band of white fibrolite-gneiss, which is continuous with the coarse, crushed Washington gneiss

and impregnated with a coarse feldspathic pegmatite in veins and irregular masses.

All along the tortuous boundary the limit of the Washington gneiss can be fixed by the presence of graphite and fibrolite in a two-mica rusty gneiss, and over the whole area the same characteristics exist, although there are many bands from which pieces much like the Becket gneiss can be taken.

A mile south of South Sandisfield, near a watering trough, a black-pyritous quartzite occurs, which is like that above the limestone in the East Lee Valley.

At the southern apex of this area a pale-pink garnet is abundant and of large size. The regular intergrowth of muscovite and biotite is quite characteristic.

Bands of black hornblende-gneiss and green pyroxenite occur just north of the State line in Sandisfield, south of A. Ducharme's house. This rock is rather bright-green, finely granular, and passes into a light granular quartzite made up almost wholly of cuboidal grains of bright-green pyroxene, with distinct dichroism to pale-brown in basal sections and with very coarse prismatic or pinacoidal cleavage. Some grains are centrally darker in color and full of dark ore grains. There are a few grains of orthoclase, plagioclase, biotite, a green mineral like epidote, and a deep-green actinolite. This rock contains no calcite, but it is clearly one of the derivatives of the limestone and is changing into an amphibolite.

In one instance, in the neck that connects Seymour Mountain with a rocky spur projecting southwest, distinct pseudoconglomerate structure appears in the graphitic gneiss. The same rock composes the whole top of the hill west of Seymour Mountain.

Above the 1,600-foot contour the entire hill is composed of coarse, warty, very micaceous gneiss, with rusty, coarse, sandy grained mass. The nodules are about the size and shape of pecan nuts and consist of coarse blades of overlapping muscovite and biotite, often with more or less dark gray from spots of radiated fibrolite. They are first orthoclase, then muscovite, then fibrolite.

The contacts can be well seen at the bridge over Buck River, a mile above West New Boston. The first reefs below the bridge are of Washington graphitic gneiss. Six rods farther is the contact with the thin-banded Cambrian gneiss. The contact is exposed again where the rock crosses the two roads northwest of Seymour Mountain, on the mountain itself and on its southeast spur, as given above, and where it crosses the brook east of Mount Pisgah, on the south line of the quadrangle.

OTIS AREA.

This area is cut off on the south side by the Tyringham Valley fault, which is continued down the valley of Clam River; on the north side it is bounded by the East Lee Valley fault, which follows the bed of

Farmington River. Between these two faults there is a central band of Hinsdale limestone and its derivatives, flanked on either side by the rusty blue-quartz gneiss.

On the west, at the north foot of Filley Mountain, fibrolite begins to appear, and ultimately replaces the blue quartz farther south. On the top of the mountain the two occur together, but the blue quartz can not be traced much farther south as an important constituent.

The eastern boundary seems to coincide with the Farmington River, and the first outcrops to the east, in the high banks, are of the Cambrian white gneiss, until, in the bluffs across the brook south of the blind road at P. Davison's, there is, at an old mine said to have been worked to a depth of 10 to 15 feet, an apparent outcrop of a pyritous wernerite rock of pre-Cambrian age. It seems to lie a little west of the bluffs of white gneiss.

The boundary then runs southwest into Sandisfield, and at the south foot of the hill, 40 rods west of H. S. Hawley's, the last house before turning off to Cold Spring, is another old mine. A deep trench runs into the hill where the white gneiss on the east and the rusty, graphitic, pyritous gneiss full of garnets and black hornblende (this is the ore) on the west are closely approximated.

The next point where the two can be seen to approach each other is on the hill west of the south end of Spectacle Pond, in Sandisfield. The apex of the hill north of an abandoned house is of the white gneiss, standing nearly vertical, with the strike shifting from north around to west, in great folds, from the influence of the fault to the south.

The western boundary is normal. The rusty gneiss rests against the white gneiss and is overturned to the west.

The boundary of the pre-Cambrian on the Cambrian is carried, both on the northwest and on the southeast, directly across the strike of the two, while whenever the two are found in immediate contact they are squeezed into superficial conformity. This is because of the lack of sufficient outcrop. If one could trace the whole boundary, I have no doubt it would run northeast in general direction, but with many sharp serratures directed northwest and southeast.

The bottom of the Farmington River Valley in Otis abounds in large boulders containing, in great abundance and often in very fine crystallization, the following minerals: wernerite in white stout crystals and large lavender masses, pale-green pyroxene in cleavage masses several inches across, titanite, hornblende, emerald-green actinolite, pyrite, and graphite.

On the hill a half mile south of the hotel is an outcrop of coarse, granular, scarcely cemented limestone, carrying red-brown titanite and grains of wernerite and coccolite, deeply excavated by weathering, from which, tradition says, two cart loads were once blown out by a mysterious explosion while the owner of the farm was in close proximity to the place.

Along the river in Otis Center there are also found many large boulders of a fine chalcedony, a very characteristic fault rock which gives evidence of the special activity of circulating solutions along the fault plane. There are, among others, very large masses of fine, white to pale sky-blue boulders, which are drusy and botryoidal in cavities. They represent the last stage of deposition, since they inclose many angular fragments of a deep-yellow jasper, showing that this jasper had been an earlier filling of the fissure, made, doubtless, by waters at a higher temperature, which were able to dissolve iron as well as silica from the gneiss.

Both these chalcedonies contain fragments of the wernerite, proving that still earlier movements had shattered the wernerite limestone, that a solution of the calcite had followed, and that, later, a cementation of the residual silicates by silica had taken place.

"SNOWPLOW" ANTICLINE OF BEAR¹ MOUNTAIN.

"Beartown Mountain. The vast pile of mountains that bears this frightful name lies southeast of Stockbridge." (Hitchcock's Final Report, p. 235.)

The great anticline of Sky Hill and Bear Mountain has been closely folded, with north-south axis, has been strongly overturned to the westward, and has then been bent around into a sharp V (with apex directed northwesterly), by the movement of the north limb of the anticline around through the east quadrant so as to point southeast. It is, of course, not intimated that these events happened successively, though it does not seem to me wholly impossible that such may have been to some extent the case. It is certainly most probable that they were nearly contemporaneous.

As a result of this posture of the rocks, the high ground, consisting of older rocks, encroaches on the limestone valley to the west by exactly the full width of this anticline. The general structure of the anticline can well be compared to one of the large double railroad snowplows formed of two vertical concave surfaces which diverge from a central prow. If the Cambrian gneiss on the north and west of the pre-Cambrian could be removed, the north and west surface of the pre-Cambrian would have the shape of such a snowplow. In other words, northeast and southwest sections across the mass present a gradually widening fan-structure as they are drawn along lines more and more distant from the apex at the northwest.

The same structure is continued for many miles to the southeast, and 1 mile south of Monterey the Cambrian conglomerate-gneiss mounts over the Stockbridge limestone in a similar snowplow anticline and is itself surmounted in the same way by the pre-Cambrian of Morley Hill.

The area of exposure of the pre-Cambrian in Bear Mountain is lunate; a narrow band extends from the apex down the crest of the

¹ See footnote on p. 13.

mountain from its northern end for 4 miles south, bends east, with an easy sickle-shape, and ends just across the road north of Livermore Hill.

The west lobe has an average width of less than a half mile. From its northern part it sends a broad lobe, a mile wide, east for 3 miles into the Sandisfield quadrangle. The western lobe is composed of the Washington blue-quartz gneiss, often strongly banded, graphitic, and very rusty. The eastern lobe, excepting its eastern end on Sky Hill, which is described below, is composed of the coarse, white, ligniform Tyringham gneiss.

A band of black amphibolite, of fine grain and well bedded, which occurs at or near the contact but within the Becket gneiss, aids in fixing the limits of the older bed.

The structure of the western lobe is that of a closely compressed anticline overturned to the west. Its axial plane strikes a little west of north for three-fourths of its length and bends around to strike southeast in its southern fourth; it dips 75° to 80° E. The best places to study the beds are where the road crosses Bear Mountain on its south end a mile north of Livermore Hill, and on the top of Sky Hill. At the former place the axis of the fold is exposed in a heavy bluff on the east of the road south of a coal-burner's hut, and is a coarse, very quartzose biotite-gneiss, quite rusty and well banded, and composed almost wholly of blue quartz.

Fifty rods to the south the amphibolite crosses the road and fixes the boundary. Fifty rods north, at the highest ground south of the last bridge over the brook, the white Cambrian gneiss can be seen in contact with the blue-quartz gneiss, dipping away from it, with many convolutions, to the northeast.

The bed of amphibolite crosses the brook opposite the schoolhouse a mile east of Bear Mountain peak, and appears in great force three-fourths of a mile southwest of that point and 100 rods southeast of the peak, where it has a width of 40 rods. From the schoolhouse it bends east and runs down the Monterey road to the boundary of that town.

The boundary of the bed continues along near the road, often marked by small hornblendic bands.

At the isolated home of Mr. Beebe, the well-known weather prophet of the mountain, the amphibolite again appears, while south of that point, in a section a mile long crossing the whole band from north to south and emerging near the beginning of the Monterey road, only the monotonous Tyringham gneiss is visible.

At the east end of the syncline is Sky Hill, rising above the former settlement of the Shakers, at Fernside, and noted as the burial place of Mother Ann, queen of the Shakers.

An area nearly a mile long and a third of a mile wide, upon the crest of the hill, is occupied by the rusty graphitic Washington gneiss, while the white Cambrian gneiss wraps round the two kinds of pre-Cambrian rocks, showing unconformity.

A bed of coarse gneiss, with a band rich in hornblende and titanite, is the southeastern apex of the pre-Cambrian rocks. Everything indicates an overturned anticline of the older rocks included in the Cambrian Becket gneiss.

The Becket gneiss is abundantly exposed over broad areas to the east and north, and strikes N. 20 to 30° W. and dips 30 to 40° W. under the pre-Cambrian. On the eastern slope of the east spur of Sky Hill the Becket gneiss rests, wavy and irregular, on the older rock, which is a stretched gneiss of light color with large grains of magnetite.

At the top and at the east aspect of this hill the typical rusty, blue-quartz, graphitic gneiss is in great force—a ragged-surfaced, well-banded, rusty-brown rock.

The bedding is expressed by bands almost an inch apart, which, being more quartzose, stand at a regular uniform level, while the intervening micaceous layers are deeply excavated by weathering, making a very rough surface. The rock is always very rusty, and at times shows an abundance of lavender quartz, but is usually so crushed that only a blue core can be seen here and there.

The boundary is beautifully exposed around the north slope of this east spur, and runs 5 rods south of two great dead trees which are visible from the whole length of Tyringham Valley below. It then runs northwest, past a large cellar of the abandoned Shaker settlement at the 1,700-foot contour northwest of the summit of Sky Hill.

All of Sky Hill for 100 feet down is of the same rusty rock. A great band of black, heavy, hornblende rock runs across the crest of the hill, and west of it is a micaless gneiss with the aspect of a quartzite. A hundred feet down the slope on the west is a very rusty, extremely graphitic schistose gneiss. All these beds are pre-Cambrian.

Going down the mountain to Fernside we pass over the whole Cambrian and Silurian series inverted, and then over the Silurian and Cambrian in normal order, and come upon the pre-Cambrian in the bottom of the valley. In order to understand this complex syncline one should consult the sections of Bear Mountain in the Housatonic folio.

MONTEREY AREA.

As a result of strong overthrusts to the west a small pre-Cambrian area appears on the south line of Monterey, between two brooks. Its south end is in New Marlboro, at the brook which crosses near the house formerly occupied by E. R. Smith, 2½ miles south of Monterey.

Here the section in fig. 10 is exposed. Beneath the dam the Becket gneiss is in place, with traces of pebbles 1 to 5 inches long. This gneiss is continuous in the field northeast of the house, and contains the beds of amphibolite which mark the neighborhood of the Cambrian contact. The rock dips northeast and seems conformable with graphitic gneiss, which appears in the yard of the house and can be traced into the great hill of pre-Cambrian rocks to the north. It is overthrust

onto the Stockbridge limestone, which appears in great force west of the house and to the south grades into mica-schist.

On the hill to the north the blue-quartz gneiss is abundant, associated with coarse graphitic gneiss. Coarse black hornblende in large cleavage pieces, rusting to red in the center, and a dark-green pyroxenic rock with remnant of limestone, also occur here.

All along the northwestern border is a sugary crushed rock, almost wholly fine granular plagioclase, with a uniform small amount of magnetite, and at times minute garnets, a little biotite, and films of muscovite. It carries also lenses of deep-green to black coarse hornblende, with centers of the coarse calcite from which the silicate has been derived. The whole is a crushed facies of the pre-Cambrian limestone on the fault.

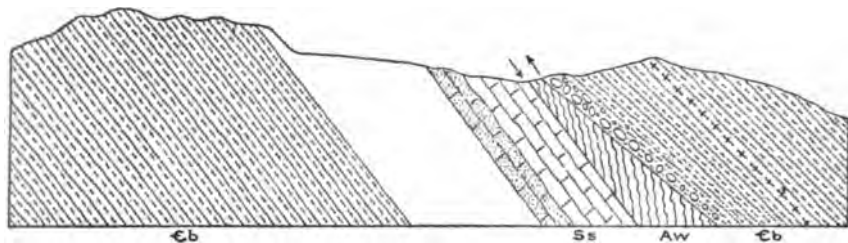


FIG. 10.—Overthrust of pre-Cambrian on Stockbridge limestone; north line of New Marlboro. Cb, Becket gneiss; Ss, Stockbridge limestone; Aw, Washington gneiss.

SOUTHERN AREAS.

The small pre-Cambrian outcrops which run south from New Marlboro village to the southern line of the town are everywhere very rusty and have often tempted the landowners to unremunerative mining, as at the Cleveland, Hotchkiss, and Wadsworth mines. Bands of impure limestone are abundant and have often been changed, more or less, to silicates. Calcareous amphibolites and pyroxenites are as a result common, and often carry a nickeliferous pyrrhotite, which at the Hotchkiss mine has furnished fine crystals.

The limestones are characterized by the abundance of sulphides of iron and by the absence of the finely crystallized silicates, of wernerite, and of various forms of chalcedony, which appear farther north, where the beds are cut by great faults.

The pre-Cambrian rocks lie in whole or in part in deep landlocked depressions, which seem to have been formed by the removal of the limestone by solution, the sinking in of the thin, flat Cambrian cover and the later removal of its fragments. The last stages of this work of removal we may ascribe to the action of the Glacial ice.

NEW MARLBORO AREA.

A mile southwest by south of Southfield, at the house of G. Lawrence, the Becket gneiss, with a band of black hornblende-gneiss, crosses the road.

A few rods north are large cliffs of the rusty, very graphitic gneiss,

with pale-green hornblende, and the boundary can be followed from there N. 60° W., making a sharp loop where it crosses the border of the quadrangle and then going northwest over the north flank of the hill, passing thus into the Sheffield quadrangle. It again enters the Sandisfield quadrangle on Collins Hill, where the Cambrian gneiss is beautifully conglomeratic,¹ and runs along just south of the road into New Marlboro and through the village to a point near a small dam east of the town.

On Collins Hill the pre-Cambrian gneiss contains the blue quartz which is so characteristic farther north.

AREA SOUTHEAST OF SOUTHFIELD.

High bluffs of the light Becket gneiss rise north of the house of J. Wade and occupy the hill to the south of it, and between emerges a small pre-Cambrian area, mainly in the valley bottom, but rising a little above it a short distance west of the house. This area is a flat triangle about 100 rods long and 40 rods wide, and along its northeast border rises a band of coarse, impure limestone and pale-green hornblende-gneiss.

HARMON POND AREA.

The banks on the east side of this pond descend almost vertically into deep water, and 3 feet above the water's edge the pre-Cambrian emerges from beneath the Becket gneiss as a band of green amphibolite with a thin band of coarse, loose, granular, coccolite-chondrodite-limestone, and a micaless gneiss with titanite and chlorite pseudomorph, apparently after titanite. Boulders of the pre-Cambrian rocks are found around the pond, but the first outcrops in the bluffs back from the water are Cambrian. (See section of Cleveland Mountain shown in fig. 11, p. 64.)

SOUTHFIELD CEMETERY AREA.

A little way up the hill from the Southfield cemetery, a mile south of the village, is a ledge by the roadside where the extremely rusty character of the rock has tempted somebody to waste time in blasting, and the ledge has been so undermined that the rock can be seen to form a low dome. Outcrops of the Becket gneiss are near at hand on all sides, showing that it is a very limited area domed up through the newer rock, which is an exceedingly rusty dark-green pyroxenite, largely hornblendic.

HOTCHKISS AREA.

Northwest of East Pond in New Marlboro, a few rods north of the house of Mr. I. Hotchkiss, a bed of massive, white, coarse limestone emerges from beneath the Becket gneiss, which is at this point a fine quarry granite, and a limekiln has been erected here. The limestone dips 25° N. on the north side of the quarry and 20° S. on the south side.

¹ My attention was called to the locality by Prof. William H. Hobbs.

It is exposed with a thickness of 10 feet, and no bottom appears. It is exceptionally pure; a few small chondrodite grains and pale-green chlorite flakes occur.

At the edge of the brook, a half mile below the house, a shaft has been sunk about 12 feet upon a group of small pyrite veins in the coarse, rusty, dark-green pyroxenite. Crystals of pyroxene an inch across can be found, generally eight-sided prisms, terminated by imperfect and rounded O faces. A coarse-bladed green hornblende also occurs. Two veins of the pyrite are 3 to 4 inches wide, bunching to a foot and showing rude cubes of pyrite 1 to 1½ inches across, and pyrrhotite in cubical masses up to an inch on a side and in fine crystals an inch long—three-sided, slightly tapering prisms with edges truncated. These crystals weather to a liver-brown; a basal cleavage develops, and the layers warp apart and spoil the crystals.

Albite occurs in druses of many-faced crystals, with beautiful play of color on the $\infty P \infty$ (010) faces. On the dumps everything is coated with a crust of a colorless sulphate.

CLEVELAND AREA.

This is a triangular area 1 mile long from east to west, a half mile wide from north to south, half on the Sheffield quadrangle and half on the Sandisfield quadrangle.

At its northern apex is the Cleveland iron mine, about 100 rods northeast of the house of J. Cleveland. The Becket gneiss, somewhat granitoid, rests nearly horizontally upon the Hinsdale limestone, which is 4 or 5 feet thick, and below this, in the hillside, is a great thickness of the coarse, light-colored Hinsdale gneiss, in which is an irregular vein of magnetite, bunching in places to a foot in width.

The limestone is a white, firm, coarse-grained rock, in most of its thickness showing only a few pale-green mica scales. Some layers are filled with green mica, buff phlogopite, deep-red chondrodite, and colorless tremolite in fine needles.

Commencing about 10 feet below the limestone the gneiss is extensively trenched to open the iron ore. The most abundant variety is a clear gray gneiss, much resembling at first sight the Becket gneiss above the limestone. It is darker gray, firmer, and the black mineral is sometimes wholly black granular hornblende in rounded separate grains with fused surfaces, very different from the same mineral in the black Cambrian gneisses. In other places the black mineral is wholly magnetite. Much of the gneiss is highly stretched, the very scanty dark mineral being a dark-green hornblende, or epidote and hornblende.

Along the magnetite vein the rock is greatly crushed. The purest magnetite is mixed with hornblende, and the folia of the white gneiss inclose rows of large hornblende nodules and masses of epidote and contain druses of albite crystals in cavities.

Coarse, friable, granular limestone, containing many small grains of

dark-green hornblende and pistachio-green pyroxene, are caught up in the crumpled rock (see fig. 11) or intergrown with the white hornblendic gneiss. This is very different in texture and accessories from the compact thick-bedded chondrodite-limestone above. It can best be looked upon as a calcareous vein stone derived from the normal interbedded chondrodite-limestone.

The contact may be seen in the edge of the woods north of the house of J. Canfield, nearly 1 mile southeast of the Cleveland house, just at the west edge of the long bluffs of contorted Becket gneiss which border the road on the north for a long way east of this house. The biotite-gneiss changes suddenly into the coarse hornblendic gneiss. The boundary turns sharply west at this point and must closely follow the road west, as the outcrops of the biotite-gneiss are abundant on the south side of the road past the southern end of the Cleveland road to the vicinity of the Wadsworth mine, 100 rods north and 10° east of the house of Mrs. J. P. Wadsworth. Here are two openings, 10 feet deep, upon a rusting bed of calcareous actinolite-schist. A former limestone bed has been almost wholly changed into balls of a granular grass-

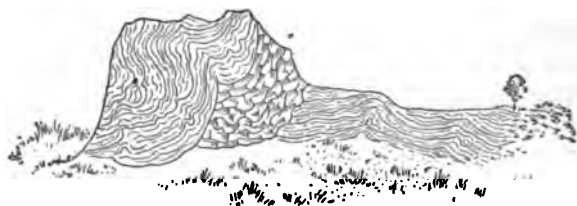


FIG. 11.—Limestone pinched into pre-Cambrian gneiss, Cleveland mine, New Marlboro.

green hornblende-biotite mixture. The limestone is pinched into the gneiss in a remarkable way, and where it is changed into hornblende rock it could be mistaken for an altered dike.

In the center of the area is the Cleveland mine proper—a shaft about 20 feet deep. The rock is a deep-green massive pyroxene-hornblende, carrying much pyrrhotite and a little chalcopyrite, considerable coarse granular calcite, and graphite. The mine was first opened as a gold mine, and I was shown a nugget of gold half as large as a pea and one of silver as large as a dollar, which were said by the owner of the mine to have been obtained from a barrel of the ore (500 pounds). The assay was made by a Boston firm. An assay made by Arno & Co., Cedar street, New York, gave \$5.50 gold and \$0.75 in silver for 500 pounds. Later assays have shown no precious metals but varying quantities of nickel from 3 to 26 per cent. This information was given me by Mr. Cleveland. The bed was being worked in 1891 by a New York firm as a nickel mine.

The structure of the Cleveland area is anticlinal. The axis is N. 35° W., and the whole is overturned to the west, so that at the northern end, where the overturn is complete, the Becket gneiss rests almost horizontally on the Hinsdale limestone and gneiss. On the southern end they stand almost vertically. Along the southwestern side the

Becket gneiss dips low beneath the older rock and is inverted. Still farther west and lower down the Cheshire quartzite rests on the Stockbridge limestone in the beautiful dome cited by Professor Dana;¹ so that going west from the Cleveland mine one has the whole series, from the pre-Cambrian to the limestone inverted, as indicated by fig. 12, showing section through the Cleveland mine and through Harmon Pond.

NORTH CANAAN AND WEST NORFOLK AREAS.

Limestone.—On the road from Norfolk that enters North Canaan at its extreme north-east corner are fine ledges of the white Cambrian gneiss. Crossing the brook

and going southwest up the hill we find a small wooded knoll just southeast of the road, which consists of the characteristic schistose nodular gneiss of the region, and shows on its eastern aspect the single outcrop of limestone which is found in the pre-Cambrian of this area.

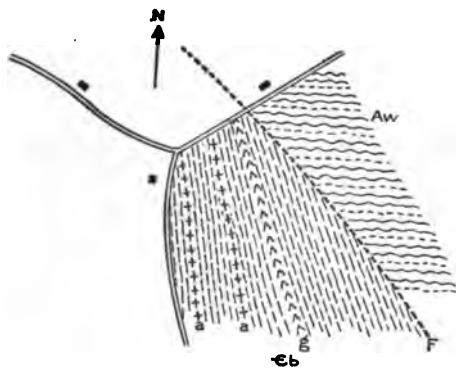


FIG. 13.—Fault contact of pre-Cambrian (Aw) on Cambrian Becket gneiss (Cb) containing granite (g) and amphibolite (a); northwest corner of North Canaan.

pite, and large blue orthoclase nodules.

Nodular gneiss.—The coarse, rusty, highly micaceous muscovite-biotite gneiss adjacent to the limestone described above is full of large pebble-like nodules, which represent ancient porphyritic feldspars, now

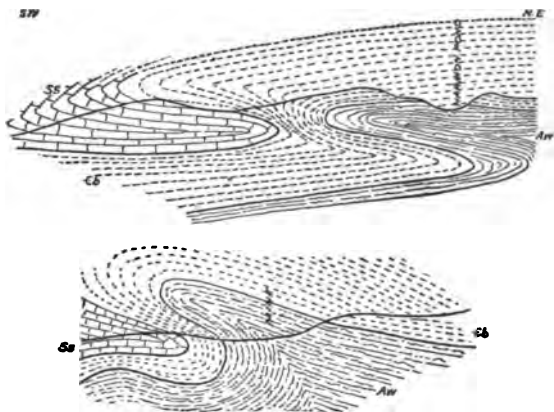


FIG. 12.—Overturned antiform in Cleveland Mountain, west of Harmon Pond, New Marlboro. Cb, Becket gneiss; Aw, Washington gneiss; Ss, Stockbridge limestone.

It is in the east edge of the woods and 10 rods from the road, and is exposed only 30 feet from north to south and a few feet in width. Prof. William H. Hobbs blasted into it for 8 feet and found it a true outcrop. The limestone dips 50° W. underneath the nodular gneiss, while a few feet to the east the Cambrian gneiss outcrops in the pasture, striking N. 20° E. and dipping 70° W. It is a coarse granular limestone of translucent grains, with rotted chondrodite, phlogo-

¹On Taconic Rocks, etc.: Am. Jour. Sci., 3d series, Vol. XXIX, p. 222. (Locality 14 on Dana's map.)

largely changed to matted masses of coarse muscovite which is filled in varying degrees with fibrolite. It also contains large garnets, and weathers to a very rough surface.

The rock contains graphite regularly, and is exactly like the rock of Seymour Mountain in Sandisfield, into which I have traced the pre-Cambrian blue-quartz gneiss of Tyringham and Otis. (See p. 56.)

Following the road a half mile southwest, to near its end on Tobey Hill, we find, south of the red house at the end of the road, the best exposure for the study of these nodular gneisses and their posture against the fault by which they touch the Cambrian on the south (see fig. 13).

The white gneiss (Gb), with beds of amphibolite and garnets, abuts against the nodular gneiss, and this rock continues with a monotonous regularity for a mile southeast, to the west foot of Ball Mountain, where it often carries a little tourmaline.



FIG. 14.—Campbell Falls section (central part given in Pl. IV), New Marlboro. Gb, Becket gneiss; Aw, Washington gneiss.

Campbell Falls section.—Following the schistose gneiss a half mile northwest from the limestone, to the point where the next road north crosses Whiting River (the brook coming from East Pond) at a fine waterfall, we find clearly shown the contact of the Cambrian gneiss on the east with the older gneiss. Fig. 14 gives the relations of the two rocks and Pl. IV shows them represented in the central portion of the diagram. All to the right or east of the water is Cambrian gneiss, which continues a little way to the left, to the foot of the vertical bluff of the older nodular gneiss which rises above the upper level of the water. The strong shear planes run in the white gneiss parallel with the falling waters, and west of the pool, at the bottom, the white gneiss can be seen dipping beneath the older rock.

South of the fault the same nodular gneisses appear in force, and one of the best places to study them is south of the road running northwest onto Tobey Hill from the point mapped in fig. 13 (p. 65) and south of the western house in the figure. Specimens from this place have



CAMPBELL FALLS, NEW MARLBORO; LOOKING NORTH.

been described by Professor Hobbs¹ as illustrations of the change of orthoclase to muscovite.

These rocks cross the railroad at the west end of the long West Norfolk cut. (See Pl. V, p. 76.) Here there is first a rusty, spangled muscovite-gneiss, containing graphite, pyrite, and fibrolite, dipping east beneath a light actinolite-garnet-gneiss, which also dips east against a granite-filled fault plane near the third telegraph pole from the entrance of the cut. It abuts against the black quartzite common at the base of the Cambrian.

The same nodular schist makes up the high ground south of the river at West Norfolk and is well represented in the ledges south of the hotel in Norfolk.

On the brow of the hill in West Norfolk, near the south line of the Sandisfield quadrangle, iron ore is found around the house of H. M. Jones, near the upper end of Lake Wungum.

Nodules in the gneiss.—The rock at Campbell Falls is a coarse muscovite-biotite-gneiss, very micaceous, with nodules, about an inch long, of coarse pegmatitic feldspar, bordered by a band of black biotite and brown hornblende. Another form is in its central part made up of a single crystalline grain of quartz, with a partial border of coarse, much-twisted muscovite, both full of fibrolite. Another form is composed of a single large crystalline grain of muscovite, full of fibrolite; and still another is of coarse granular microcline, without fibrolite.

The groundmass of the rock is a finely foliated mixture of muscovite and biotite, often intergrown, often much twisted by pressure and finely foliated, but without fibrolite.

The rock, as found in the ledge west of the limestone on Tobey Hill and in boulders southeast of Ball Mountain, coming from the same area contains nodules of muscovite full of tufted fibrolite, and large grains of orthoclase also containing fibrolite. The nodules are separated by a finer grained, confused muscovite-biotite groundmass. A quartz-feldspar mosaic often surrounds the nodules, being formed by their partial crushing.

The fibrolite is found in quartz, feldspar, and muscovite, and not in biotite. It is often in a sort of sagenitic network on the C face of the mica, arranged parallel to its prism faces.

Prof. William H. Hobbs has described these nodules from the boulders and found the cleavage and Carlsbad twinning suture of the feldspar retained in the mica.¹ He gives the following analysis made by Dr. W. F. Hillebrand, of the United States Geological Survey.

¹ Pseudomorphs after feldspar from Norfolk Township, Connecticut: *Am. Geologist*, Vol. X, p. 46.

Analysis of nodules from Norfolk Township, Connecticut.

	Per cent.
SiO ₂	76.32
Al ₂ O ₃	15.87
Fe ₂ O ₃	.53
FeO.....	.28
CaO.....	.28
K ₂ O.....	4.55
Na ₂ O.....	.54
H ₂ O at 100°.....	.20
H ₂ O above 100°.....	2.01
TiO ₂	Trace.
SrO.....	Trace.
Li ₂ O.....	Trace.
P ₂ O ₅	Trace.
Total.....	100.00

We examined the locality together and then considered the nodules to have been pebbles, as mentioned in his article, an opinion which I have since abandoned.

SOUTHEASTERN AREA.

Above Riverton, on the Farmington River below the Sandisfield quadrangle, is a large outcrop of the Hinsdale limestone and the associated hornblende and pyroxenic rocks, rising in the center of a broad area which may be associated with the Washington gneiss through the Sandisfield area just described, though the blue quartz is absent, being replaced by fibrolite, while the presence of graphite and of both micas, the rustiness, and the coarse, ragged, somewhat schistose texture of the gneisses distinguish them from the Cambrian above.

A characteristic rock in this area is a dull black biotite-gneiss, highly fibrolitic and rusty, spangled with large flakes of muscovite and often abounding in large, irregular garnets. The band extends far northeast and southwest, but nearly its full width is found in the Sandisfield quadrangle. Where it enters the quadrangle, east of Mount Pisgah, it is a sugary-crushed, rusty, graphitic hornblende-gneiss.

PYROXENITES AND AMPHIBOLITES.

The passage of the limestone into a coarse-granular leek-green pyroxenite is very common; a large bed of this kind appears at A. Ducharme's, at the south apex of the Sandisfield pre-Cambrian area. (See p. 56.)

A knob of a similar rock projects above the level of the track at the signal house west of the Middlefield station. It is a calcareous diopside rock derived from the pre-Cambrian limestone and projecting into the Becket gneiss. Other similar projections appear in the cut nearer the limestone. It has disseminated crystals of a black hornblende, luster-mottled (poikilitic) by the earlier diopside, and changes into a green amphibolite which contains little plagioclase and no ore.

Because of the interest which attaches to the origin of amphibolites, special attention is called to the change of the limestone in Hinsdale into black, massive amphibolite and hornblendic gneiss, both by the formation of interstratified beds of various dimensions, and by an alteration progressing from both the top and the bottom until only a few feet of limestone remain at the center, and also to the Cleveland area, where the limestone is pinched into the gneiss like a dike and then partly changed to amphibolite (fig. 11).

The amphibolite—which occurs in continuation of the limestone at the Alderman farm at Becket Center and which has been quarried as emery and copper ore, and the exactly similar rock found adjacent to the Coles Brook limestone 1 mile east of the Alderman farm, are more difficult of assignment. This is a black, massive, granular rock quite like the altered Cambrian dikes described below. It carries garnet, and the black ore which it contains is associated with titanite (leucoxene); the colorless ground is largely quartz. The rock is much like the Lee gneiss above East Lee, described on page 33, and I have associated it with the Lee gneiss, as a derivative of the calcareous transition beds above the Hinsdale limestone.

ANALYSES OF PRE-CAMBRIAN LIMESTONES.

The following analyses of pre-Cambrian limestones are taken from Hitchcock's Final Report of the Geology of Massachusetts, page 80. The other Berkshire analyses in this table are of the Stockbridge limestone:

Analyses of pre-Cambrian limestones.

	1.	2.	3.	4.
CaCO ₃	54.80	56.25	51.66	58.31
MgCO ₃	44.98	31.56	39.48	28.61
Fe ₂ O ₃	.22	1.12	.91	1.24
Impurities		11.07	7.96	11.84
Total	100.00	100.00	100.01	100.00
Sp. gr.	2.77	2.78	2.77	2.84

1. Lee, 1 mile east of village; burned for lime. This is from the hill above East Lee.

2. Middlefield; Coles Brook; white.

3. Blandford; white. This is a great bowlder from the Coles Brook bed, found south of the village of North Blandford.

4. Becket, southeast part; magnesian.

CAMBRIAN SYSTEM.

An inspection of the map will show that the Cambrian gneisses and quartzites cover more of the surface than do the rocks of any other system.

In the area between the pre-Cambrian and the Stockbridge limestone it is helpful to carry out the distinction between the lower portion of the system—the Becket gneiss, which was originally largely conglomeratic and is now chiefly a muscovite-gneiss with some quartzite—and an

upper portion which was originally largely a quartz sand and is now changed to a more or less micaceous quartzite—the Cheshire quartzite, very generally characterized by the presence of minute crystals of dark-brown tourmaline, although the quartzite sometimes extends to the base of the system.

This quartzite is locally replaced by a mica-schist, which is often greatly corrugated. On the east side of the pre-Cambrian the Cambrian is largely a biotite-gneiss and is completely gneissoid up to the hydro-mica-schists and lacking in tourmaline.

UNCONFORMITY AT THE BASE OF THE CAMBRIAN CONGLOMERATE.

Five rods east from the mountain cottage on the hill high above Dalton Station the conglomerates, themselves nearly horizontal, can be seen resting upon the vertical beds of the older gneisses which strike N. 80° E. One can follow the junction in the cliffs south and then for a mile southwest down the mountain side, to the brook above J. S. Barton's, with excellent exposure, as indicated in fig. 4, page 40. It continues up the side of Warner (or Day) Mountain, and on south through the woods for 2 miles to the great fault described hereafter (p. 92). On the opposite side of the anticline, along the east slope of the same hill, the same unconformity can be seen, though the outcrops are poorer. Everywhere the old gneisses strike N. 80° E. and are nearly or quite vertical, while the conglomerates, nearly horizontal at the top, take a low dip westward down the west side and eastward down the east side of the long hill, and before it was cut through along the crest of the hill they mounted over it symmetrically.

The unconformity is thus striking, abundantly exposed, and extends for a long distance. The same unconformity clearly exists along the west flank of the West Washington anticline (shown well at P. Conroy's house), a mile northwest of the Becket reservoir.

Around the great Hinsdale anticline there is everywhere a general apparent conformity, but there is very commonly a discrepancy of 10° to 30° in the strike, while the dips uniformly agree in being low to the east; but the whole anticline is so forcibly pushed over westwardly and flattened, and the outcrops on the exact junction are so few, that it gives little important evidence on the subject.

The pre Cambrian at the Coles Brook anticline is thrust very irregularly through the Cambrian, and the unconformity is well shown in the description of the section at the mouth of the brook (see p. 41), and is apparent in the whole length of the band from the contact of the Cambrian gneisses with the different members of the older series. It is more beautifully shown a mile north of the railroad cutting, where the road comes down off the mountain and crosses the limestone near the site of the burned house of H. Hawes. As seen in the figure (fig. 15), the Cambrian gneiss wraps in easy folds over the vertical pre-Cambrian limestone, which is accompanied by a rusty biotite-muscovite-

gneiss, with tourmaline and coarse graphite, and on the top of the hill, where the gneiss is worn through, the limestone appears.

A nearly vertical secondary schistose structure is present in much of the gneiss. It is a typical Becket gneiss, with many striated octahedra of magnetite, and at the sharp bend in the road it contains an 8-foot bed of a fissile black amphibolite with films of biotite. This makes a very beautiful slide under the microscope. Around the many grains of magnetite an abundant growth of titanite (leucoxene) appears, swelling into larger crystals in a limpid ground of untwinned plagioclase grains. It is probably an altered eruptive rock.

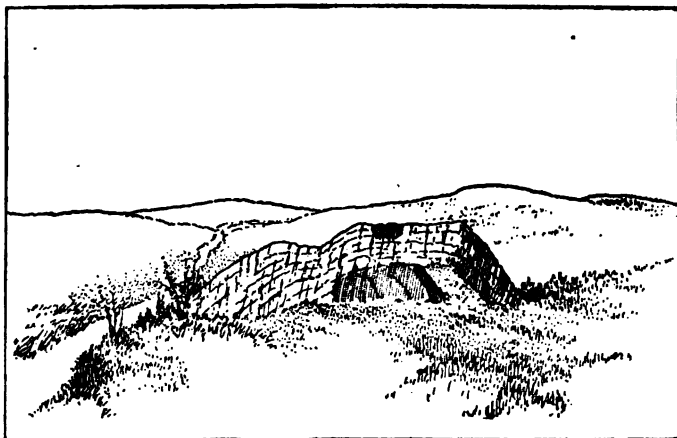


FIG. 15.—Cambrian gneiss folding over pre-Cambrian limestone unconformably; Middlefield.

CONGLOMERATE-GNEISS (BECKET GNEISS).

In the northwestern part of the area the broad band of light-colored gneisses which encircle the old blue-quartz gneiss of the Dalton anticline is as uniformly characterized by the abundance of muscovite as the older series is by that of biotite. The latter mineral is not always absent in the newer rock, but when it does occur it is in small, scattered flakes, not in connected films.

All the other characteristics of the older series are conspicuously absent, except that the blue quartz occurs in grains and pebbles, plainly secondary. It passes gradually upward into the Cheshire tourmaline-bearing quartzite.

The base of these gneisses is often a heavy bed of the most clearly developed conglomerate of quartz pebbles—white, black, and blue, commonly white, with rarely a pebble of feldspar or gneiss—from 5 mm. to 100 mm. in length, uniformly well rounded, and all arranged parallel to a common plane. They are sometimes apparently flattened parallel to that plane to quite broad sheets, in one case to round-edged plates of quartz 150 mm. by 100 mm. by 10 mm. These pebbles are generally inclosed in a large quantity of groundmass, which is changed into a

mica-schist or a micaceous quartzite by the development of more or less muscovite, and many tourmaline crystals encrust the surface of the pebbles, often in radiating groups.

This conglomerate bed is continuous and can be traced for miles across Hinsdale and into Washington. It is best studied at the Dalton clubhouse and across to the south in the open pasture, represented in fig. 4 on page 40. The conglomerate is here so beautifully distinct, the ground so completely changed to a muscovite-schist, and the complete unconformity to the underlying pre-Cambrian so well exposed, that this is the best locality in Massachusetts for the study of all the relations of the two formations.

The growth of rosettes of tourmaline on the pebbles and the shearing of the conglomerate into a complete gneiss along narrow bands, 6 inches wide and at right angles to the bedding, on either side of which the pebbles are but slightly flattened, is especially notable. From the clubhouse flat one will do well to follow the contact down the slope to the brook (see fig. 4), where the Cambrian and the pre-Cambrian can be seen in contact, and also to go across to the east of the pasture, to the point indicated in the right-hand part of the figure, where the gneissoid development is more complete, although the pebbles are in places quite distinct.

From the Hinsdale station one may go a mile north along the railroad, to the long rock cutting, and see the same gneiss entangled in a warped and overturned syncline and more highly metamorphosed and contorted.

One of the best places to study the series from the blue-quartz gneiss up to the Cheshire quartzite, and especially the relations of the conglomerate to the pre-Cambrian gneiss and the transition of the conglomerate gneiss into the sugary tourmaline-quartzite, is in the northwest corner of Washington, where a blind road, not on the Survey map, runs north from a schoolhouse to the house of H. C. Congdon.

The blue quartz is extremely abundant and of rich color. Allanite is present, and parts of the ledges near the barn and spring are crushed into a granulite, which can only be distinguished as pre-Cambrian by its association with other pre-Cambrian rocks and by its position below the Cambrian. On the west it is covered unconformably by a fine muscovitic conglomerate-gneiss, which is more gneissoid farther up from the base, and where a wood road crosses the brook it becomes a tourmaline-bearing quartzite, slightly muscovitic. Next west, and thus higher up in the series, it is a fine, white, massive quartzite, forming the first range of hills and becoming schistose as one goes down into the limestone valley.

It is in places a very feldspathic quartzite, and by the decomposition of the feldspar becomes quite regularly porous, having formerly found some use as a buhrstone.

While through all the western half of the Becket quadrangle the

lower part of the Cambrian is everywhere more or less conglomeratic near the older rocks and more or less a quartzite in its upper part, in the broad eastern band the metamorphism is more severe, and this division can not be carried out.

Down the east border of the area across Windsor and Peru half-obliterated traces of pebbles occur here and there in the lower half, but the whole upper portion is mainly muscovite-gneiss. The gneisses are marked by a deficiency of feldspar, by the friable, granular character of the mass, and by the absence of all accessories except tourmaline and magnetite.

A mile northwest of Peru Center the true dip is marked by sandy layers an inch thick interposed between 2-inch schist layers, though in much of the area the structure is probably secondary. Around Peru Center the rock is a gneiss in thin flaggy beds, with the mica mostly biotite. The degree of metamorphosis increases steadily southward.

Across Becket the rock is a friable, well-banded but often thick-bedded biotite-gneiss, like that of the Monson quarries but even more massive and granitoid, and this quarry granite borders the Coles Brook and the Alderman pre-Cambrian limestone beds, the regular granitic texture seeming to depend on greater dynamic metamorphism accompanying the sharp upfolding of the limestone. Where it occurs along the railroad from North Becket to Coles Brook it is a good building stone, and in the quarries by the railroad the passage from the flaggy to the massive varieties can be clearly seen. Just west of the Coles Brook crossing the rock beside the railroad is flaggy and in flat undulations. In the quarry above, it is massive, thick-bedded, and granitoid, and is somewhat mixed with pegmatite in small veins.

In the south part of Becket the gneiss becomes a thick-banded, completely granitoid, light-gray gneiss, which furnishes the fine quarry stone of the Chester Company's quarries in the extreme southeast corner of the town, and the same rock extends south into Otis. A thin section of the rock appeared highly crystalline, very fresh, and of completely gneissoid structure. The large plagioclases were full of small crystals of biotite and of black rods—some stout and straight, some minute and curved. The quartz grains were full of sheets of cavities with large moving bubbles. The biotite was everywhere intergrown with muscovite, though to the eye the rock seemed purely biotitic. It gave no indications of strain, but rather showed signs of complete recrystallization.

In Monterey and in the area south of New Marlboro bordering the pre-Cambrian the Becket gneiss is quite normal across the whole length of the quadrangle to the south. It is much of the way a massive, white, granitoid quarry gneiss; the biotite is jet black. Very small garnets are numerous, and the rock is characterized by minute magnetite octahedra. These seem to be dissolved through the influence of lichens, and the

rock then weathers white. After rains they accumulate by the roadside as iron sands.

One or two bands of a jet-black, fine-grained biotite-hornblende-gneiss occur about one-fourth of a mile east of the boundary with the older rocks. There is rarely any trace of pebbles in the gneiss along the boundary or elsewhere

The amount of quarry gneiss is inexhaustible, and the rock from the large quarry on Ball Mountain, Norfolk, can not be distinguished from the Becket and Monson quarry rock. In Otis the white gneiss branches on the pre-Cambrian, and its western lobe runs down west of Filley Mountain to the Tyringham fault, while its border portion continues down the eastern part of the quadrangle inclosing Great Pond and the Otis reservoir. It is a very uniform biotite-gneiss. The jet-black biotite is generally disseminated through the rock, at times concentrated in rounded or elongated blotches or in distinct banding. It generally bleaches at the surface to a dead white, but always contains much magnetite in minute octahedra. At times it is strongly muscovitic, as where the East Granville road crosses the east line of the quadrangle, and at the northeast slope of Noyes Mountain. Where it enters the Sandisfield quadrangle it is largely garnetiferous, but this characteristic disappears to the south. Only one small hornblendic bed occurs in it. This is east of D. Goddard's, a mile east of Otis Center.

Considerable excavation for iron has been made west of T. Fay's, a mile farther east, beginning more than fifty years ago. The gray gneiss is here a little more impregnated with magnetite than usual and carries hornblende.

In Otis the rock generally occurs in smooth, white ledges, with a fine-grained granitoid structure, very free from fissures, and breaking in large blocks, or, while breaking in equally large and firm blocks, showing a flat or wavy contorted banding from the arrangement of the biotite. It at times weathers into a ragged and deeply pitted and seamed rock, as in the remarkable bare ledge which starts from the southeast lobe of Otis reservoir and runs over the top of Noyes Mountain, a famous fox run. It nowhere shows any trace of conglomerate structure, and I have at times tried to refer portions of it to a certain wholly crushed facies of the Washington gneiss, but on comparison, especially under the microscope, it seemed plainly not to belong to that type. The Becket gneiss at its junction with the pre-Cambrian across Sandisfield and Tolland has been quite fully described in tracing the upper boundary of the latter (see p. 55) from the apex of this South Sandisfield lobe, to the north of which it is greatly corrugated, around to that village. Typical quartzite and a black pyritous quartzite accompany the boundary and lie well down toward the base of the Cambrian, where the rock is usually gneissoid, so that in the southern part of this area I have not tried to carry out the distinction between the basal gneiss and the quartzite above, which is so well developed in

the Becket region. All across Sandisfield the Becket gneiss is very generally a fine-grained, gray, quarry gneiss, of good quality for building purposes.

AMPHIBOLITES IN BECKET GNEISS.

On page 68 reference is made to pyroxenites and amphibolites derived from pre Cambrian limestones.

East of the Connecticut the Becket gneiss is often black, from excess of the shining black biotite and fine granular hornblende, assuming the aspect and relations of a crystalline schist, and seeming to have the same origin as the conglomerate-gneiss itself, into which it passes and of which it is, in my opinion, a mere ferruginous and calcareous variant.

In tracing the Becket gneiss of the western region south from Hoosac Mountain I did not find any hornblendic beds until the locality at H. Hawes's, in Middlefield (see p. 70), and the Chester Company's quarry in Becket were reached.

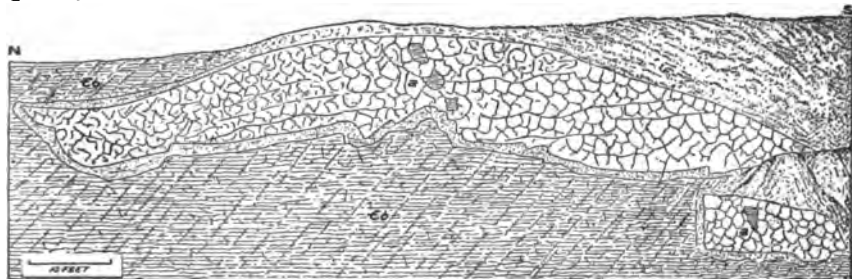


FIG. 16.—Amphibolite dike (a) in white granitoid Becket gneiss (Cb) with pegmatite contact rim (p); quarry, Becket.

At the latter place a great mass of a fine, jet-black, massive and friable biotite-amphibolite extends, with a width of 12 to 15 feet, across the east wall of the great quarry (see fig. 16). It tapers to a point at the north end, and a separate or faulted portion of the main dike appears at the south end. It contains blocks of the white gneiss and, what is very peculiar, is separated from the inclosing white, massive biotite-gneiss by a quite continuous band of a coarse muscovite granite or pegmatite a foot wide, a phenomenon which is repeated several times farther south, as at the Ball Mountain quarry and at the West Norfolk cut.

Under the microscope the rock shows in a fresh, limpid ground of granular quartz and plagioclase-feldspar (the latter gave in plates parallel to M, the optical figure of oligoclase), and abundant grains of hornblende, biotite, and magnetite. In many of the occurrences farther south the grains of each mineral have nearly a common size, giving the slide a very regular look. Here many smaller flakes of the same minerals are inclosed in the feldspars.

Some of the black ore grains are surrounded by titanite (leucoxene). It is not, however, nearly so abundant as in the Middlefield bed described on page 70. Titanite generally characterizes the amphibolites

in the Cambrian beds, which I have considered to be derived from gabbros or diabases, and is absent in the similar beds which I have supposed to be altered calcareous deposits.

From this point on, going south, the hornblendic beds grow more abundant in the white gneiss and come to be quite characteristic of the basal beds of the Cambrian near the contact with the underlying pre-Cambrian. This is so uniformly the case in the region surrounding the Bear Mountain anticline that it gives a safe indication of the position of the boundary where it is concealed. The beds are generally without structural indications of eruptive origin, are often more biotitic than hornblendic, and, as they are always interbedded with the gneisses, have probably had a similar sedimentary origin. They are too small to be represented on the map.

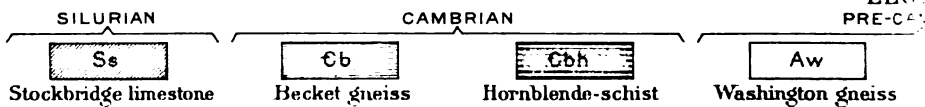
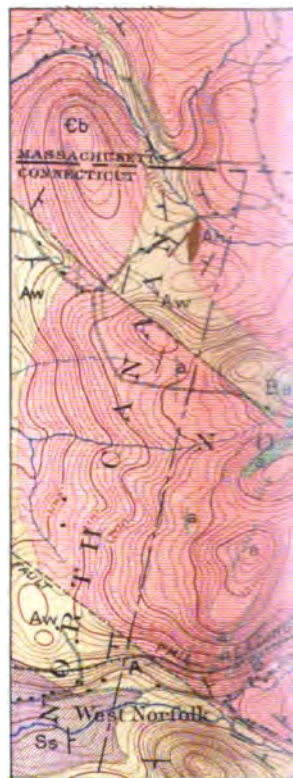
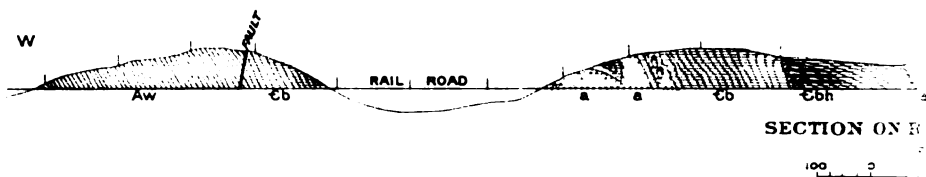
The hornblendic rocks are even more abundant in Norfolk, and both the sedimentary and the intrusive kinds are represented. Haystack Mountain, Ball Mountain, and the high hill to the east are largely composed of amphibolite and seem to owe their height to its durability. In the quarry on the east face of Ball Mountain is a black dike exactly like the Becket dike previously mentioned. The country rock is the granitoid white Becket muscovite biotite-gneiss. It contains inclusions of a black rock much like the dike. The dike is wholly inclosed in the gneiss, is 8 feet wide, and extends 5 rods south before being covered. It is cut by a dike of pegmatite a foot wide—a clear, gray rock with idiomorphic quartz, much plagioclase, and shining, black biotite which is coarser than the biotite of the gneiss.

The rock is the same black granular rock, suggesting fine-granular tourmaline, but slides cut from different parts of the mass vary materially, while the hornblende and the black ore surrounded by titanite are the same. In one slide the biotite is of even size with the hornblende grains and free from inclusions, and the abundant colorless ground is largely granular quartz; in the other slide the large porphyritic biotite scales inclose all constituents except hornblende, and the ground is a fresh, granular, mostly untwinned feldspar, with the border of each grain differing sharply from the center.

The whole top and west slope of Ball Mountain are composed of the same black, massive, hornblende-biotite rock.

In the southeast wall of Ball Mountain the light gray gneiss wraps round the rectangular south end of the black, massive amphibolite exactly as if that had been a more massive foreign body in the conglomerate-gneiss at the time of the folding. This is like a diabase dike, but it is also like a displaced limestone bed, and either one may be changed into an amphibolite. (See p. 64.)

Haystack Mountain, on the contrary, is made up of a highly contorted hornblendic gneiss, generally biotitic, pyritous, or garnetiferous, thin foliated and carrying intervening thin bands of a white gneiss a foot or so in width, which look like dikes in the black rock.

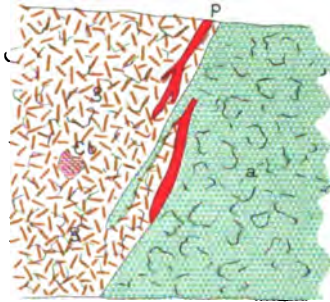
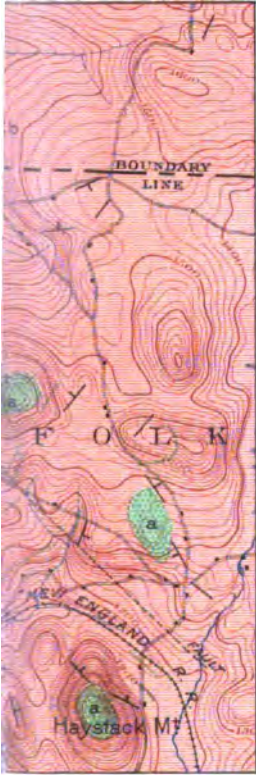


NORFOLK RAILROAD CUT AND MAP



A-B ON MAP

300 400 FEET



DETAIL AT 2 ON SECTION

Scale

10 FEET

1 2 MILES

W
E

ERUPTIVE

Windsor limestone

Pegmatite

White granite

Amphibolite

SHOWING LOCATION, WITH DETAILS.

The great railroad cut west of West Norfolk Station shows all the relations of these rocks to the best advantage. It is illustrated by the section on Pl. V. Entering the cut from the west the rusty pre-Cambrian gneisses (Aw) occupy the first 28 rods. At first they are granitoid and carry graphite. They are succeeded by light actinolite-gneisses carrying garnet. Both minerals are indicative of the near presence of limestone in the rock. These are all characteristic pre-Cambrian peculiarities. Then comes a fault marked by a pegmatite (p) layer, and this is followed by the light biotite-gneisses (Eb), which carry near the base a heavy band of thin-bedded micaceous quartzite.

On passing an interruption in the cut we again come to the same gneisses, in which is a great dike-like mass of amphibolite (a), or what may be taken to be a wholly altered basic eruptive.

This is immediately followed by another entirely similar bed, which includes great masses of the gneiss and has a sharp but irregular boundary against the inclosing hornblende-gneiss (Ebh), which latter, from the analogy of the similar bed described below, seems to be older than the two dikes described above and to be of sedimentary origin. Then follows the foliated and finely twisted amphibolite bed (at 1 in the section), which is given in detail on Pl. V. The contorted foliation of the inclosing schist runs parallel with the walls of the black bed; and both are partially sheared asunder and quartz veins occupy the distant shear planes.

Near the east end of the cut is a broad bed of a fine-grained white granite (g), which on the east abuts against the foliated amphibolite (at 2; see detail figure) and includes great angular blocks of it, together with the common gneiss, thus showing that both these rocks are older than the granite. At the east end this granite is cut by two dikes of the black massive amphibolite, into which it sends tongues, thus showing that this massive amphibolite is newer than the foliated amphibolite. The granite has produced a marked metamorphic effect upon the black rock. An outer layer of the latter a half inch wide has lost its banding and is of much coarser grain.

In both cases a selvage of pegmatite separates the amphibolite from the white granite. These foliated amphibolites lack some of the peculiarities of the amphibolites derived from eruptives and resemble those derived from limestone described on page 69.

The two dikes just mentioned share all the properties of those described above from near the west end of the cut, but differ considerably in minor matters.

The dike, with inclosures, at the twenty-first telegraph pole from the west end of the cut is the normal type of the Cambrian eruptive amphibolites or metadiabases. It is a blackish gray, massive, fine-grained rock, made of shining hornblende needles, biotite scales, and a small amount of white interstitial matter just visible to the eye.

Under the microscope plagioclase appears, rarely twinned and with

small angle of extinction. Many large grains, which seem exactly like quartz, are biaxial and positive, and so are plagioclase. The hornblende is in jagged angular cuboidal grains, with strong absorption and deep colors—*a*, bright yellow; *b*, yellow to greenish yellow; *c*, blue green; $b > c > a$ Ex. 23° — 29° . Menaccanite occurs and leucoxene is abundant.

The garnet-amphibolite from the dike at the east end of the railroad cut is with the lens not distinguishable from the other metadiabases of the region. It is a massive, fresh-black, fine-grained rock, mostly black granular hornblende and white granular plagioclase.

Under the microscope it is quite peculiar. The hornblende has rather less absorption and is composed of large aggregations of small scales, sometimes polarizing together and grading into large grains which are centrally filled with large needles placed parallel to the cleavage.

The garnet grains are free from inclosures and are surrounded by a beautiful radiated aggregate of plagioclase blades which expels all the colored constituents and has exactly the aspect of the secondary water-deposited albite filling cavities in the Triassic diabase from Greenfield.¹ The resemblance is so exact that one may feel sure that this limpid plagioclase is also water deposited. The plagioclase molds the garnet grains and radiates from them. The two minerals occupy angular spaces, as if they replaced a porphyritic mineral.

The magnetite is surrounded by a very ferruginous biotite, but never by titanite (leucoxene). There is a little quartz present.

CHESHIRE QUARTZITE.

The basal conglomerate of the Cambrian originally passed up into a sandstone which is now represented by a white quartzite, often largely muscovitic, always deficient in feldspar, and quite regularly characterized by small black or dark-brown tourmalines. It is at times simply a white friable quartz-sandstone, often dug for glass making; at times a thin fissile muscovite-quartzite, which can be seen to change along the strike into muscovite-schists or white gneiss; and at times a tough, massive quartzite.

In the high ground north of Dalton village the quartzites are present in great force, are at times calcareous and at times muscovitic, but are not developed as distinct gneisses upon the Becket quadrangle. They are hard, massive quartzites where crossed by the roads. At the southwestern corner of the high ground, as represented on the map, they are white, sugary, glass sands, which were entered to a depth of 180 feet in digging for a well on Mr. Thomas Allen's farm, Grasmere, just south of Coltsville Station.

They are at times metamorphosed into distinct gneisses. Of such a character is the fine long exposure in the railroad cutting which extends from the railroad crossing of the Hinsdale-Dalton road, near the Cath-

¹ Bull. Geol. Soc. Am., Vol. VIII, 1897, p. 59.

olic cemetery, north to the line between those towns. The beds sweep in a broad curve, with strike northeast to northwest, and represent the center of the overturned syncline between the two anticlines, and thus the top of the series.

The rock is a muscovite-schist, at times a sericite-schist, highly contorted. It dips eastward, as forming the east flank of the Dalton anticline; and entirely similar but less altered beds occupy the other (western) slope of Warner Hill, dipping westwardly on the other slope of the anticline. Here, in the brook bed above J. S. Barton's, the rocks above the conglomerates are white mica-gneisses or quartzites, and certain beds are a pure quartzite full of quite large drusy cavities, now partly filled with kaolin from the alteration of feldspar. The rock rarely contains small tourmalines and magnetites.

The metamorphosis of these beds plainly decreases toward the north and west in the region under discussion, so that the minimum of change appears in the northwest corner, on the brook last mentioned.

The quartzite along the west slope of the Dalton anticline is very thin bedded, and the greatly corrugated and discordant layer of the mica-schists upon it makes it probable that part of its thickness may be concealed by a fault.

South of the South Dalton fault, on the high ground southeast of Pittsfield, the quartzite widens into a broad area. It lies nearly horizontally and rises eastwardly in soft undulations. Where the Pittsfield-Washington road crosses the corner of Dalton and makes a large bend to the east the rock carries so much muscovite that it deserves the name of a schist, but it does not approach in type the higher schists and has all the characteristics of the quartzites (tourmaline, sandy structure). The same is true on the next road south, south of S. Hines's, where mica-schist is shown on Professor Dana's map. These quartzites pass around the north end of the Washington anticline in a broad flat syncline in the conglomerate-gneiss, which extends far out over the high ground in a very unusual position for such soft and slightly metamorphosed rocks. Just where they are cut by the line of latitude $42^{\circ} 25'$ they overhang Sackett Brook in bluffs more than 100 feet high.

They are dug as glass sands at the extreme southeast end of this syncline south of Ashley Lake, in the middle of Washington. They are everywhere characterized by fine tourmaline needles and are generally muscovitic in greater or less degree.

KAOLIN FROM THE QUARTZITE.

Professor Dana has called attention to the decay of the quartzite south of Ashley Lake, in Washington, and to the formation of sand therefrom, and explains this decay as due to the decomposition of the feldspar in the feldspathic portions of the sandstone.

The quartzite, which varies from the hardest to the most friable and

from massive to thin bedded, has at times quartzose layers alternating with thin seams of soft kaolinized feldspar.

Many kaolin beds of western New England occur in quartzite, and are washed out from the decomposed quartzite. This is true of the largest of these deposits, that in the southwest corner of New Marlboro, near the Canaan boundary. The kaolin is sandy and contains quartzite fragments.

Feldspathic quartzite occurs near the line between Lenox and Washington. Large cavernous blocks lie over the fields, with cavities an inch or more long.

Dr. C. Dewey says it is wrought into millstones after the manner of the Paris buhrstones, and is known as the Pittsfield buhrstone.¹

Feldspar still exists in some of the cavities. Prof. E. Hitchcock recognizes the feldspathic character of the rock in his Massachusetts Geological Report of 1842, saying (page 587) that the buhrstone is "a variety of gneiss rock whose feldspar has decomposed and disappeared, and in which quartz was greatly the predominant ingredient." The name "gneiss," which has been given it, is not so far out of the way as might at first seem, for some of the rock contains, besides feldspar and quartz, a little mica.

- The hearthstone quartzite quarried less than a half mile south of this locality, which affords the best hearthstones of western New England, contains black mica, in very minute scales disseminated through it, like much of the quartzite elsewhere.

Professor Hitchcock mentions another locality, 4 or 5 miles south of the spot where millstones are prepared, at which the rock "may be seen in all stages of the process between gneiss and buhrstone."²

QUARTZITE BRECCIA.

I have mentioned the breccia found along the South Dalton fault. The massive quartzite is shattered, the fragments being often moved on one another and cemented by limonite. It was first described by Dr. Chester Dewey in 1824,³ and is mentioned by President Hitchcock in his report of 1841 (p. 588). He enumerates it in his catalogue of the State collection in 1841 (Nos. 604-606) and 1856 (quartzite, Nos. 59, 60, and 107, 108) as brecciated quartz; cement hematite. It is attributed by Professor Dana to the wedging open of the fragments by "the extremely slow action of the depositing limonite."⁴

I have found it so closely associated with faults that I have no doubt that it is a fault breccia, produced by friction along the great transverse faults, the fragments being afterwards cemented by infiltrating iron solutions at so low a temperature that the cement is limonite.

¹ Am. Jour. Sci., 1st series, Vol. VIII, p. 17.

² J. D. Dana: Am. Jour. Sci., 3d series, Vol. XXVIII, p. 448.

³ Am. Jour. Sci., 1st series, Vol. VIII, p. 18.

⁴ Pseudobreccia, by J. D. Dana: Am. Jour. Sci., 2d series; Vol. XXVIII, p. 451; Vol. XXIX, p. 57.

TRANSITION OF LIMESTONE INTO SANDSTONE.

In the single spur which projects into Lake Garfield, in Monterey, from the middle of its southern shore is a ridge of the white limestone resting upon a highly calcareous sandstone and dipping 50° S.

At the south end of the Monterey pre-Cambrian (see p. 60), south of the brook opposite the E. R. Smith place, the pure white limestone is full of white pyroxene crystals and quartz veins and grades into a rusty biotite-schist. It is sandy in some places and black and flinty in others.

A few rods north of the village of New Marlboro, and west of the north road, is a white, friable, micaceous sandstone, which is pounded to a white sand by the feet of cattle. It is very calcareous and lies almost horizontal in the Becket gneiss, into which it passes.

Along the south slope of Dry Hill, northwest of New Marlboro, 80 rods northwest of D. S. Powell's house, is a row of outcrops, 125 rods long, of the Stockbridge limestone, resting as a thin layer upon the banded micaceous quartzite. It wraps round projections of the schist, dipping away from them on all sides, and passes gradually into the schists below.

SILURIAN SYSTEM.

HOOSAC SCHISTS.

Windsor mica-schist bed.—The anticlines of pre-Cambrian gneiss along the eastern side of Berkshire County are flanked east and west by light-colored conglomerate-gneisses, and these are followed on the east side by a series of mica-schists, at first garnetiferous, then feldspathetic (porphyritic), and still higher up sericitic.

The careful studies of Professor Wolff¹ have traced these schists around the north end of the Hoosac anticline and down its western flank to where they run out onto the gneiss as a narrow band which finally disappears just northwest of Savoy Hollow. In this passage out onto the gneiss the mica-schist lies in a syncline in the gneiss running southwardly, and it is probable that the mica-schist described below is the continuation of the same bed.

The boundaries of the bed can be rudely defined by boulders west of Windsor Hill, nearly 3 miles south of the above-mentioned terminus of the Hoosac schists in Savoy, and abundant outcrops of the rock soon appear and continue in a high, narrow ridge to the Hinsdale line, just east of the reservoir.

It can be best studied at A. W. Warren's. It seems to lie in a westwardly overturned syncline in the Cheshire quartzite, which lies in the newer gneiss, but with only a narrow seam of the latter separating it from the old pre Cambrian graphite-gneiss.

It strikes N. 10° to 20° E. and has high dips to the east, but is for the

¹ Mon. U. S. Geol. Survey, Vol. XXIII, p. 80.

most part so twisted and contorted that no prevailing directions appear. It is a coarse, black, garnetiferous mica-(biotite) schist, highly graphitic or coaly, causing the black color. The garnets are of the form 110 and small. Quartz veins with sulphides occur.

Coltsville mica-schist bed.—The whole hill east of and overlooking Coltsville and forming the western foothill of Davis Hill, northeast of Dalton, is composed of a dark lead-gray mica-schist or phyllite, greatly contorted and abounding in fine quartz veins with large quartz nodules which look like pebbles. The rock is plainly graphitic and contains a few garnets. It dips southeast beneath limestone.

Dalton bed.—Following west down Barton Brook, on the west slope of Day Mountain, from the contact of the older gneiss and the conglomerate-gneiss at the clubhouse (see fig. 4, p. 40), one passes over the whole of the latter and a great thickness of the white quartzite-gneiss lying stratigraphically above the conglomerate, all having a strike N. 40° E. and dipping 30° W. beneath another bed of these schists. The nearest outcrops of the quartzite to the schist are at the road crossing of the next brook south, so that only a small thickness of intervening strata remains concealed.

The schists are here greatly contorted, strike irregularly N. 70° E., have high dips to the west, and are plainly discordant to the gneisses below.

These schists advance westwardly to the railroad, and at the foot of its embankment runs the Housatonic River. At the Carson & Brown Company's paper mill on this stream, just opposite the schist, the boring of an artesian well went down 135 feet through limestone containing a 20-foot bed of quartzite, and at that depth the drill dropped 3 feet, in a water seam said to have been full of worn pebbles, onto a surface of the same black schists, in which the boring was continued 9 feet. I have compared fragments of the schist from this boring with the adjacent ledges and they are identical. This brings these schists into the same position as the schists previously mentioned at Savoy and Windsor. On the other hand, these Dalton schists differ from the schists which succeed the white gneisses on the east in Middlefield and Becket.

Mica-schist of Dry Hill in New Marlboro.—The mica-schist which wraps around the quartzite of Dry Hill in New Marlboro and grades into the Stockbridge limestone occupies precisely the same stratigraphical position as the Dalton schist. It is composed of thin bands of a white, sugary quartzite, one-fourth of an inch to 1 inch wide, with equally thick intervening layers which are quite micaceous. The mica is fine grained and generally muscovite, though sometimes much biotite is present. High up the hillside the rock is a dark mica-schist, its dark color due to excess of biotite and hornblende.

Eastern band.—At the base of this formation a dark, highly garnetiferous mica-schist forms the passage bed from the Becket gneiss to the main portion of the series.

The latter has the habit of a mica-schist, although it is generally quite feldspathic. Small rounded crystals of albite, scattered porphyritically in the mass, have in crystallizing often cemented several grains of quartz together.

Both micas are present and the rock is generally quite dark, from the abundant biotite. It shares with the following formation the greasy feel from the hydration of its muscovite.

The base of the bed is exposed on the road lying east of Peru Center, at D. E. Ingalls's, the second house to the south after leaving the village. It is here a coarse and corrugated feldspathic mica-schist, full of garnets as large as raisins.

Two miles northwest of Peru Hill, at the stone schoolhouse, the upper boundary of the Hoosac schist upon the Rowe schist is exposed for a long distance on the bare hill 50 rods east of the schoolhouse. The rock is a gray porphyritic gneiss—a rock with the habit of a coarse sericite-schist but abundantly porphyritic and with small oval spots of white feldspar. It is well exposed east of Bancroft station on the Boston and Albany Road, beginning with the mouth of Factory Brook and extending a half mile east. At the base it is a coarse sericite-schist, full of garnets one-third of an inch across, and the same bed extends north to Middlefield Center and beyond. In the upper part the garnets are absent, and sandy layers alternate with the more micaceous bands. This continues to the bridge east of the station.

The next accessible section of the series is along the road west from Chester station, just within the limits of Becket. Where, at the south-east corner of the Becket quadrangle, the road goes south from Walker Brook to the Chester Company's quarry the brook cuts a contorted, light-gray, thin-bedded biotite-gneiss, with layers two-thirds of an inch thick, strike N. 15° W., dip 70° E. It has muscovite on foliation faces and much of it is soaked with pegmatite.

A little east, halfway to the next house, a highly muscovitic saccharoidal gneiss is kneaded in with a highly garnetiferous, rusty mica-schist, of quite coarse grain, which forms the basal layer of the terrane under discussion. Strong, coarse mica-schists follow, mainly coarse films of muscovite scales and an arenaceous quartz ground with no bands or nodules of infiltrated quartz, few garnets, and rarely blotches with feldspar aggregates. A thin section of the rock from the east of Becket (E. B. Richards's) shows a gray, rusty, muscovitic gneiss; raveled and ragged intergrowths of muscovite and biotite and a mosaic of quartz grains wrap round porphyritic "augen" of albite, which in places shows extinction according to two laws and the granophyric structure in every variety and of great beauty. The garnets are centrally filled with brightly polarizing black rods and long blades of biotite.

ROWE SCHIST.

Only a narrow band of the Rowe schist runs down the eastern border of the sheet for half its length. The small porphyritic albites disappear and the rock becomes a softer sericite-schist blotched with green, due to chlorite spots derived from altered garnets. Going east from Bancroft station to the third bridge one finds the boundary and a sudden transition from the albitic schist below. Along the railroad two bands of amphibolite occur in this formation before the edge of the quadrangle is reached. Along the east line of Becket, east of the Chester Company's quarries, it contains a gray cyanite, which includes small garnets with the centers filled with black grains. The cyanite is often changing into muscovite. (See Pl. I, fig. 6.)

Where the schist enters the Sandisfield quadrangle it is a hard, ragged, contorted muscovite-biotite-schist barren of accessories, slightly rusty and quartz veined; the zigzagged bedding goes N. 40° W., the cleavage N. 50° W. Higher up it has small hornblende-schist layers and is in places garnetiferous and of greasy feel.

STOCKBRIDGE LIMESTONE.

Only a narrow portion of the white crystalline limestone which underlies and has conditioned the broad Housatonic Valley, enters the area on its western borders and extends far east into broad depressions in the older rocks in Dalton and Tyringham and into smaller recesses south of the fault on the south line of Dalton and at East Lee. Its boundary is thus for 10 miles a straight line parallel with and near the western edge of the Becket quadrangle, while the broad sands of the Housatonic conceal nearly every portion of the limestone in the low valley bottom.

The scarp of the older rocks, which looks down on the limestone valley, is offset to the west in Bear Mountain, and on the southern half of the area the eastern boundary of the valley limestone lies far west of the territory covered by the map. The rock also extends eastward in a great lobe far out over the highlands in Monterey, and two smaller lobes enter the area at New Marlboro and at West Norfolk. In its northern portion it is mainly a calcareous carbonate and is for the most part free from accessory minerals. I have collected rutile and brown tourmaline in the quarry at Coltsville. It is a white-to-gray marble, everywhere quarried locally and furnishing good building stone in inexhaustible quantity, so that the location of quarries is mainly dependent upon the proximity to railroads. Much has been written about a flexible variety of the marble (see Calcite in lexicon, p. 107) occurring near Pittsfield.

Farther south the extensive quarries at Lee are within the limits of the area considered, and from these quarries much marble has been shipped to Washington, Philadelphia, New York, and Albany. Here some beds of the rock are filled with a white-bladed tremolite, which is represented in every mineral cabinet.

This limestone is thickly covered in the bottom of the Tyringham



HYDES FALLS.

Valley. For a long distance north of the fault it is absent, and in this distance the springs and wells on the north of the fault give soft water and those on the south of the fault give hard water. At Mr. D. Clark's and eastward the limestone is preserved on both sides of the fault, but is very thin. All the springs are of soft water.

The limestone that runs horizontally high up on the south side of the Tyringham Valley at Fernside is the common, gray, barren Stockbridge marble. On the hillside across the strike the pure limestones grade into gneiss, through a large series of calcareous schists, often very rusty. The series is thus inverted and is the upper limb of a small fold overturned to the north, its axial plane dipping south into the mountain.

On the other side of Bear Mountain the limestones dip northeast into the mountain; they can not go under it, as its nucleus is pre-Cambrian. There is thus some form of fan structure present here, as was suggested to me by Prof. T. Nelson Dale. (See section on the Bear anticline, p. 58.)

The Monterey limestone grades in every direction into a sugary calcareous quartzite, and this, with the exceptionally heavy cover of till, makes it impossible to put accurate boundaries on the map. At the branch in the road south of the outlet of Lake Garfield is a broad area of a white, sugary limestone with much white pyroxene overlain by a rusty jointed, black, pyritous quartzite. The accompanying plate (Pl. VI) shows a beautiful anticline in this limestone at Hydes Falls, $1\frac{1}{2}$ miles south of Monterey.

Farther south other remnants of the marble exist on the surface northwest of New Marlboro, and several instances of its passage into the Cambrian gneisses and quartzites are given.

Of 25 analyses of the Stockbridge limestones given by President Hitchcock,¹ 12 show it to be pure calcium carbonate. The remaining samples are strongly magnesian but quite free from silicious impurity, while in 5 analyses of pre-Cambrian carbonates the rocks are nearly pure dolomites with an average of 11 per cent of silicious impurities.

GEOLOGY OF FERNCLIFF RIDGE IN LEE.

CAMBRIAN QUARTZITE.

The geology of the prominent ridges which rise within and just east of the village of Lee (see map, Pl. VII) is complicated by the unexpected appearance of an outlier of the Cambrian tourmaline-bearing quartzite in the midst of the normal Silurian series.

This quartzite forms a peculiar ridge, which starts with Ferncliff, in the middle of Lee, and is a picturesque steep-sided mass of native rock, in whose eastern side an interesting cave has been formed by the falling of the jointed quartzite from the vertical face of the cliff.

¹ E. Hitchcock: Geol. Report of Mass., 1841, passim.

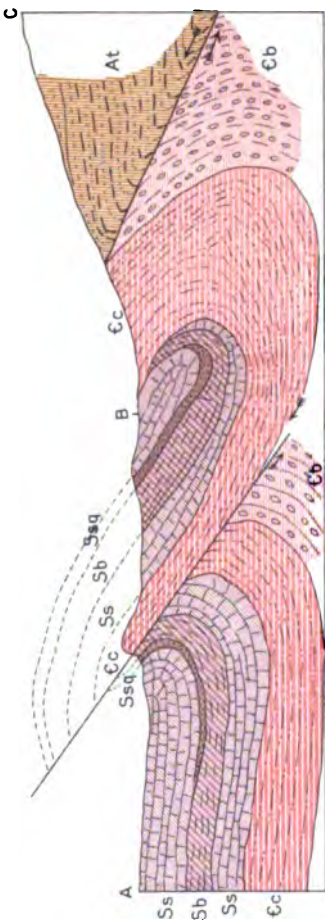
The ridge has been cut through by the river, but rises immediately on the north side and runs a mile farther northwest, presenting vertical cliffs to the east and lower bluffs to the west, where its shape is masked by a thick coating of drift. It ends abruptly at the south end of Laurel Lake, its northern and western faces showing 100 feet or more of vertical or overhanging cliff.

Lithology.—In Ferncliff the Cambrian series is represented by a thin-bedded micaceous quartzite, quite gneissoid in its granular texture and its irregularly disseminated biotite scales, and although it is slightly feldspathic it is not sufficiently so to be called a gneiss. It is uniformly fine sandy granular, and abounds in minute well-formed brown tourmalines in six-sided prisms. It is full of small lenses and pockets of quartz, and the tourmaline, in irregular aggregates, is much concentrated in and around these small veins and in their prolongations, being here much larger, some prisms reaching fully an inch in length.

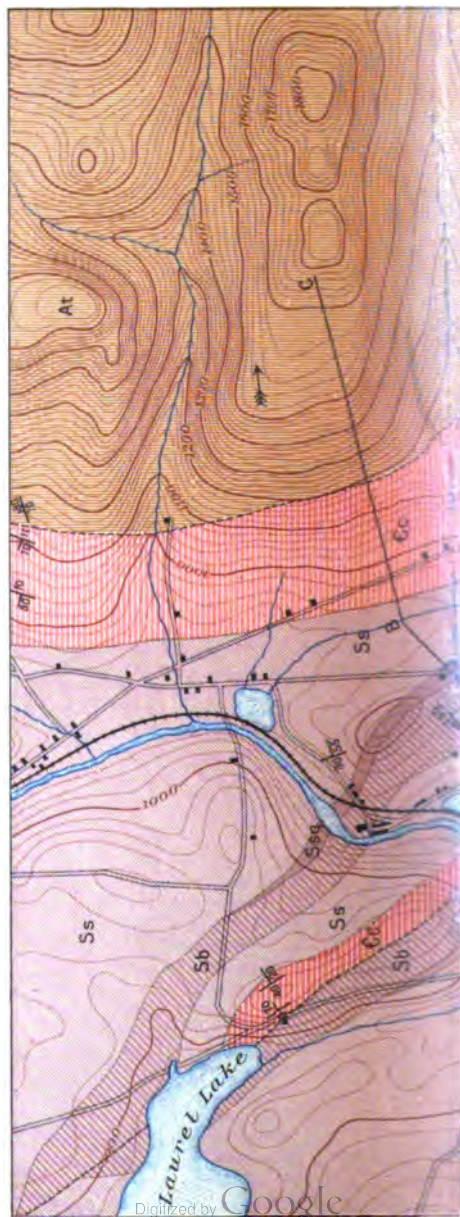
This bed, 40 or 50 feet thick, makes the crest of the ridge, and beneath it is a more micaceous quartzite or arenaceous mica-schist, always having a sandy quartz base, but often dark gray in color, owing to the abundance of biotite mixed with the muscovite. This also regularly contains tourmaline, in shapeless groups of needles, clear down to the edge of the river at the north foot of the hill. The same conditions exist in the ridge to the northwest. The rock is tourmaline-bearing from top to bottom, except in the middle of the east face of the steep hill which forms its north end, where there is, in considerable force, a pure white quartzite containing only a few minute pyrite cubes. It is, however, more granular than the Silurian quartzite to the east and more regularly banded, and layers immediately above and continuous with it contain much mica and tourmaline.

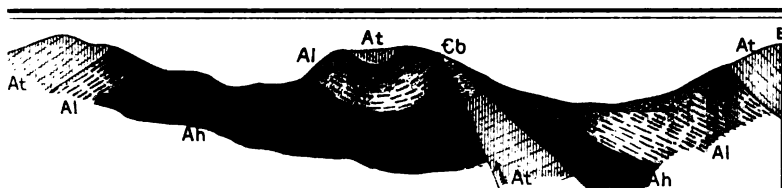
Structure.—In Ferncliff the rock is much contorted in the west face of the ridge; its beds dip east into the hill, with high angle, and emerge in the same direction, with low dip to the east as a whole but with large low undulations of the beds to north and south and with low dips to the west in some places, as at the cave.

On the north face of the Ferncliff hill the beds dip first 20° E., then 30° E., where they are on a level with the Silurian quartzite to the west; 60 feet lower, at the river bank, they are nearly horizontal, with low dip south. At the north end, in the same way, the dip is 70° to 80° E. all the way up the west face, with low easterly dips on the east side. In the high ground of the valley border, several miles to the east, the equivalent of these rocks appears as the Cheshire quartzite, which graduates into the Becket gneiss, and they are here, for a long distance north and south, characterized by an abundance of minute stout tourmaline prisms. They are much more highly metamorphosed than the Silurian rocks with which they are here associated.

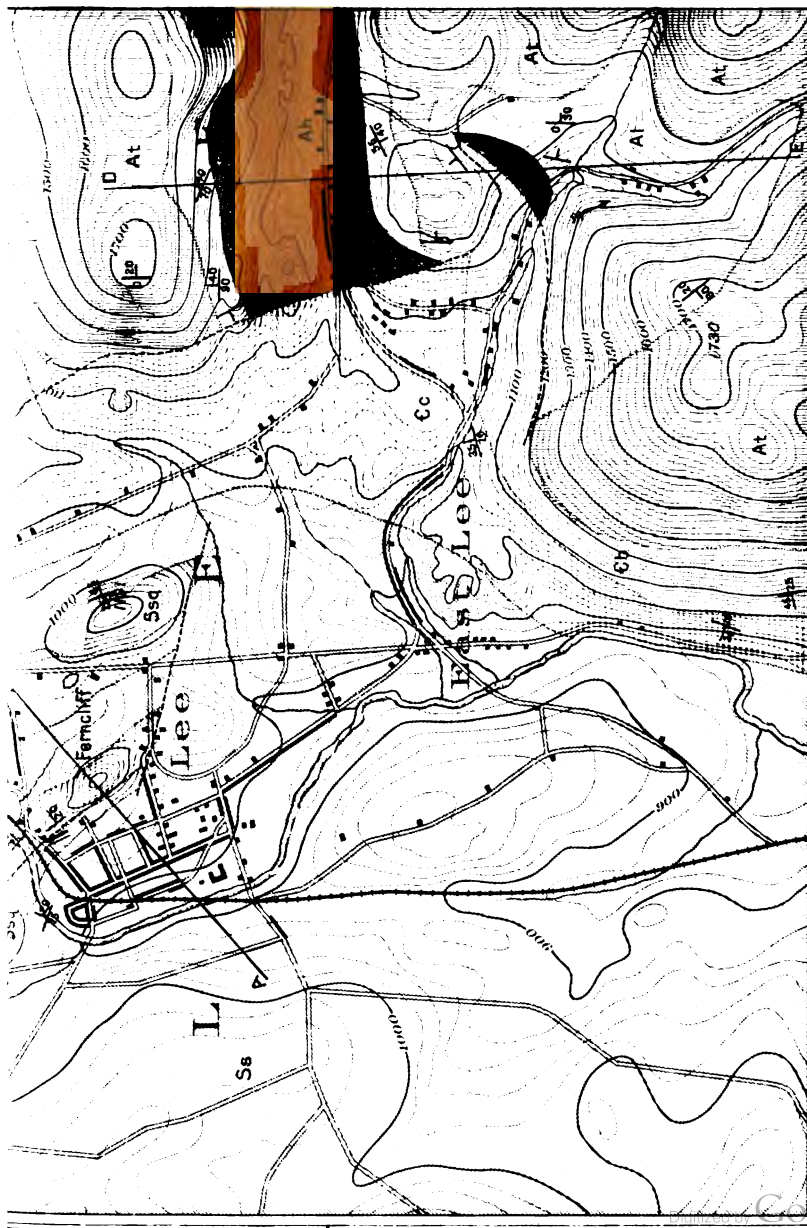


FERNCLIFF SECTION A-B-C ON MAP





EAST LEE SECTION D-E ON MAP



GEOLOGICAL MAP OF FERNCLIFF AND EAST LEE

Scale of miles



1898

SILURIAN SERIES.

LOWER LIMESTONE.

The lower band of the Stockbridge limestone which appears in this area is deeply buried in the low valley bottom and rarely exposed at all. At the railroad crossing in the north edge of Lee village, opposite the Columbia mills, where on the map the eastern quartzite band crosses the road and railroad, is a section which shows all the remaining rocks of the area in excellent exposure, all dipping eastward in apparent conformity, and just south, along the railroad, the lower limestone is also well exposed in the cutting. It is full of phlogopite in bands, especially at the top, of altered pyrite in pentagonal dodecahedrons, of granular colorless muscovite, and of quartz grains. Its calcite grains are much twinned.

It folds around a large lens of a very coarsely crystalline and limpid marble, and is as a whole so much more crystalline, translucent, and filled with minerals than the soft, fine, sugary limestone of the upper bed as to strongly suggest that it may belong to the pre-Cambrian limestone, like that of the East Lee Valley. I could not find chondrodite or pyroxene in it, and consider it a Stockbridge limestone rendered more highly crystalline than usual, perhaps by the influence of faulting.

The accompanying analysis of a specimen of this limestone, from the railroad cut in Lee, also goes far to prove that the rock is to be associated with the Stockbridge limestone. The analysis was made by Mr. George Steiger in the laboratory of the United States Geological Survey.

Analysis of limestone from cut west side of railroad, north of Lee village.

	Per cent.
SiO ₂	0.95
TiO ₂	None.
Al ₂ O ₃	.09
Fe ₂ O ₃	None.
FeO.....	.10
CaO.....	54.75
BaO.....	None.
MgO.....	.66
K ₂ O.....	.15
Na ₂ O.....	.02
Si ₂ O.....	None.
Water 100°-.....	.08
Water 100°+.....	None.
SO ₂	.05
P ₂ O ₅	.03
CO ₂	43.88
Total.....	100.16

I have elsewhere brought together (see p. 69) four analyses of the pre-Cambrian limestones of western Massachusetts. They are all nearly pure dolomites and contain an average of 11 per cent of siliceous impurities.

In a list of 25 analyses of the Stockbridge limestones 12 are nearly pure calcium carbonate, and those which contain magnesia are nearly always free from siliceous impurity.

BERKSHIRE SCHIST.

This mica-schist, which is well exposed just east of the railroad crossing on the foregoing section and in many places to the south as well as along the southwest shore of Laurel Lake, is a felted mass of warped red-brown biotite scales, generally of quite ragged appearance, rusting readily, and without accessories.

SILURIAN QUARTZITE.

The quartzite which appears near the schoolhouse just west of Ferncliff, and which has been recently opened for road material across the river to the northwest, agrees exactly in composition with that of the ridge a mile east of Ferncliff. It is the usual pure, massive, pale-yellow, vitreous quartzite.

It diminishes rapidly in thickness toward the west and north. At the south end of the east band it composes the whole of the massive hill just east of Lee (1,131 feet high), while where it crosses the railroad it is less than 50 feet thick. Farther north the rocks are everywhere covered, but all the indications of topography point to its entire disappearance, as at the north end the mica-schist ridge slopes down gradually into the low limestone plain, whereas a strong ridge would rise to the east if the quartzite were present. The quartzite west of Ferncliff is also only about 50 feet thick, and seems to thin out to the northwest so that it ceases to have influence upon the topography.

UPPER LIMESTONE.

This is the common Stockbridge limestone, white or pale gray, friable, generally pure in this vicinity, except that tremolite is abundant in the quarries to the south of the town.

FAULTS.

The representation of a north-south Ferncliff fault is justified by the close approximation of the Silurian quartzite to the Cambrian quartzite in Ferncliff, followed by the similar approximation of the Silurian mica-schist at the north end. It is drawn parallel and symmetrical with the main Lenox fault, which runs at the foot of the mountain to the east, as an overthrust subordinate to the main one, and most simply explains the structure of the region.

Justification for the hypothesis of an east-west fault is found in the fact that on reaching this line the two strong quartzite ridges suddenly stop and the whole area before them lies at the low level of the limestones, so deep indeed that over a square mile there are no outcrops at all. It is thus much more probable that these resistant beds are faulted down

than that they form the surface across to the edge of the mountains, where they appear again in undiminished thickness.

This fault, prolonged easterly, runs up the East Lee Valley, where it or another fault south of and parallel to it, which is given with query on the map, terminates the Lenox fault and is marked by the overthrust of the pre-Cambrian on the Cambrian. It also runs parallel to the great Tyringham Valley fault to the south.

SIGNIFICATION OF THE NORTHWESTERN THINNING OF THE SILURIAN QUARTZITE.

I have elsewhere shown that the Tyringham and East Lee valleys were early blocked out because of the solubility of the Hinsdale limestone, and this thinning out of the coarse sediments, represented by the two quartzite bands (see Ssq, Pl. VII), along lines radiating from the mouth of the East Lee Valley, may mark a time of exceptional elevation of the Berkshire Valley border and of strong drainage through the long East Lee-Otis depression. In other words, the quartzite and associated band of Berkshire schist represent the remains of the delta deposit of a stream flowing west down the East Lee-Otis Valley during Lower Silurian time.

FAULTS.

HINSDALE FAULT.

This fault runs north and south through the village of Hinsdale. Along the whole western border of the Hinsdale anticline north of the Plunkett reservoir the Washington graphitic gneiss is absent and the Lee gneiss comes successively into contact with the Cambrian Becket gneiss, the Washington gneiss of the Dalton anticline, and the Stockbridge limestone.

A mile south of Hinsdale, at the top of the hill just west of the large outcrop of limestone near the bridge over the railroad, and again 90 rods west of the last inhabited house (C. D. Barrett's) on the blind road running north from the cemetery, the Lee gneiss can be seen in immediate proximity to the Becket gneiss. The fine-grained micaceous quartzite (Cambrian) has a strike N. 10° W. and a dip 65° W. The amphibolite and banded gneisses (Lee gneiss) adjacent on the east have a strike N. 50° W. and a dip 80° W.

Farther north, at J. Hanrahan's, south of the road running east from Dalton, the Lee gneiss carrying allanite is for a long distance in immediate proximity to the great outcrops of Stockbridge limestone, showing that the fault is one of great importance and concealing the whole Cambrian and Upper pre-Cambrian beds.

DALTON FAULT.

From the high iron bridge near the Dalton railway station the crumbling white Stockbridge limestone can be seen to form the north bank of the Housatonic for a long way west, while the fluted surface of the massive Cheshire quartzite forms the steep south bank.

At the ruined pier of a proposed bridge this fluted surface dips 80°

N. in the upper portion of the bluff, 50° and 40° in the lower part, and represents the fault surface, being horizontally ground and slickensided by the horizontal thrust of the fault. The limestone appears in the northern bank of the narrow stream to the next iron bridge, where it includes quartzite beds and forms the bed of the stream, with a constant strike N. 20° E. and a low westerly dip of 20° , as at the Carson and Brown paper mill, just west. Here the adjoining rock on the south of the fault is a dark, corrugated mica-schist, abundant in the hills to the south, and in boring an artesian well at this mill and 2 or 3 rods north of the stream the auger went through the limestone for 135 feet and then dropped 3 feet onto the surface of the mica-schist, which was bored 9 feet. I found chips from this boring identical with the schist in the hill to the south. This gives the fault here a hade to the north about the same as the quartzite plane mentioned above. The well record is interesting and is given below.

The faults on the north and south of the Dalton anticline were formed by the crushing together and the uplifting of this anticline, and an inspection of the map will suggest that the two areas of mica-schist north and south of the fault may once have been continuous, and the part to the north have been pushed eastward by the throw of the fault.

It may have been a muddy band sent out over the bottom of water where for the most part limestone was forming, and have been continuous eastwardly with the remnant in Windsor and the Hoosac schists farther east.

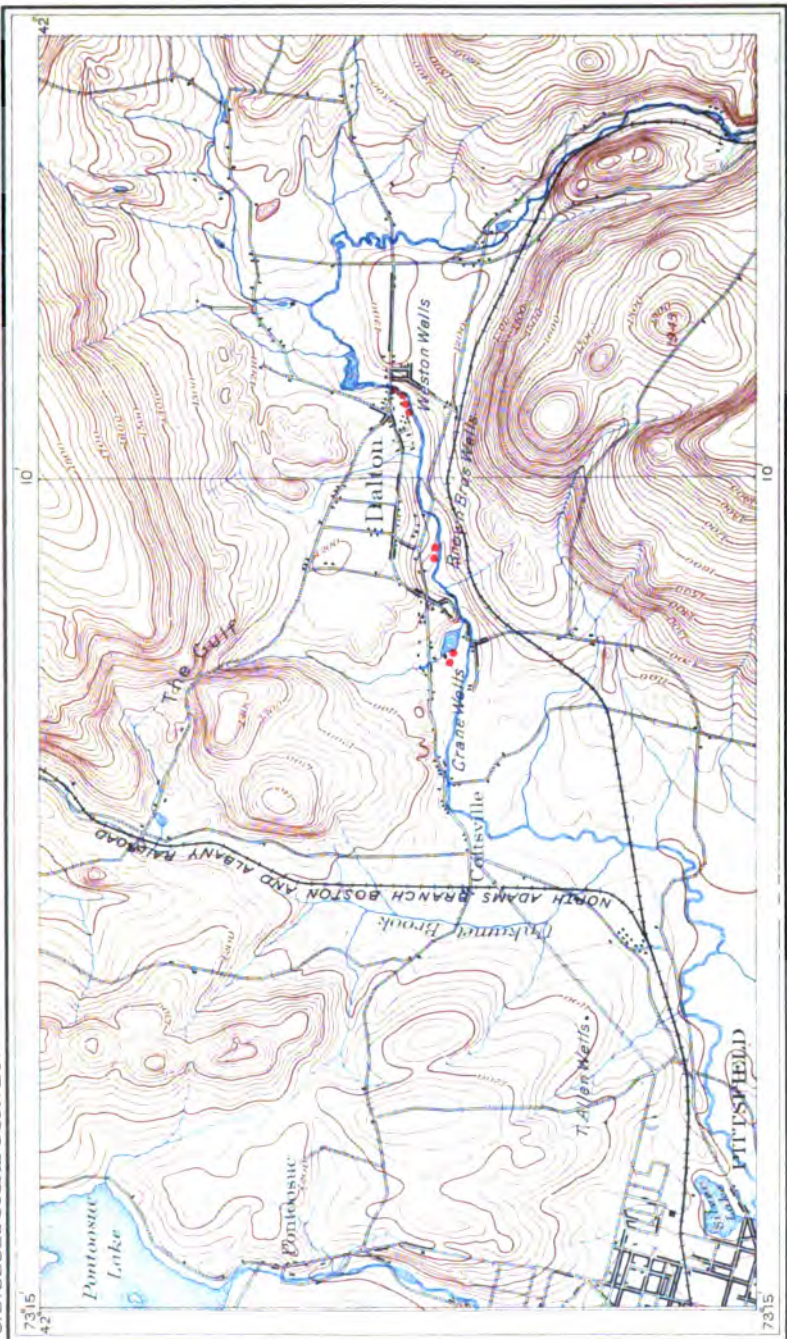
ARTESIAN WELLS UPON THE DALTON FAULT.

The great paper-making mills at Dalton owe much of their high reputation to the abundant artesian water, of excellent quality, obtained from very shallow wells bored upon the Dalton fault. (See PL VIII.)

At the Carson and Brown mill, beside the Housatonic River, in the west part of Dalton village, two interesting artesian wells have been bored. One was commenced March 7, 1884, by D. Dull, of New York. The following record was given me by Mr. Brown:

Record of well borings at the Carson and Brown mill in Dalton in 1884.

	Feet.
Soft rock	25
Hard rock	84
All way hard rock	98
Little water ran over	99
Soft rock	101
Soft rock	102
Very soft rock	104
Very soft rock	109
Very soft rock	114½
Very soft rock	117
Very soft rock; first water run	122
Very soft rock; increased water run	126
Very hard rock	131½
Broke through to soft rock and gravel 3 feet deep; water doubled	135
Solid rock again	138
Continued 9 feet in the same solid rock	147



A. H. Ross & Co. Lith. Baltimore.

ARTESIAN WELLS ON DALTON FAULT

Scale



The well supplied 740 gallons a minute of the purest water. The upper rock was limestone. The drill fell in a cavity formed by solution of the base of the limestone by water circulating along the plane of the fault. The lower rock was the corrugated mica-schist, as shown by samples preserved.

In 1853 a well was bored on the west side of the mill near the river by S. S. Gilman, of Springfield. The following record was preserved:

Record of well boring at the Carson and Brown mill in Dalton in 1855.

	Feet.
Rock blue lime	24
Rock blue lime	24-37
Gray band; first water.....	37-40
Gray lime.....	40-67
White belt; large water vein, flowing well.....	67-71
Increase of water	71-100

“The rock is soft lime mixed with soapstone.” The soapstone was probably the decomposed micaceous portion of the limestone.

An analysis of the water gave the following results:

Analysis of water from artesian well in Dalton.

[Parts in 1,000,000=140.3 solid.]

	Parts.
SiO ₂	8.80
Al ₂ O ₃	12.80
CaO.....	33.15
MgO.....	23.06
K ₂ O+Na ₂ O	22.54
FeO.....	Trace.
Cl.....	3.55
CO ₂	36.40
CaCO ₃	59.15
MgCO ₃	35.06
NaCl.....	5.85
SiO ₂	8.80
Al ₂ O ₃	12.80
K ₂ O.....	18.64

The wells in the village of Dalton to the north and east lost their water when the first well was opened. Other wells have been bored along the same fault, at Mr. Byron Weston's mills farther east, but the wells bored at the Crane mills to the west were unsuccessful and were plainly not along the line of the fault. The following report on the wells at the Weston mills, 250 rods east along the same fault, has been prepared for me by Mr. W. L. Tower, civil engineer in Dalton:

Number of wells, 5, of which 4 are in use:

No. 1, the Bonanza, is 239 feet deep and was bored in winter of 1883-84. First flow of water tested January 24, 1884, showed 366 gallons per minute. After further boring more water was obtained, and the flow has perceptibly increased since the well was completed. The latest test shows a flow of 550 gallons per minute with a

pump lifting the water 18 feet out of well. The boring drills and part of the apparatus were lost in this well, and it is thought that this fact diminishes the flow of water.¹ The rock is reported to have been principally very soft limestone. Operations in boring this well were very much delayed and hindered by caving. It was bored by Daniel Dull, of New York City, who saved samples of the rock passed through in boring the Bonanza and Deep wells.

No. 2, Deep well; 511 feet deep; bored in fall of 1883. Flow, 260 gallons per minute. Bored by Daniel Dull. Rock passed through medium to hard limestone and a vein of very flinty rock at a depth of about 300 feet.

No. 3, Chamberlin well; 150 feet deep; bored 1856-57. Flow, 120 gallons per minute. Bored by Mr. Gilman.

No. 4, Defiance well; 76 feet deep. Flow, 28 gallons per minute. This well is about 400 feet northeast of the Bonanza well. Surface rock in the immediate vicinity, as uncovered in summer of 1895, soft seamy limestone. Bored by Jesse Button, Springfield, Massachusetts. An analysis, made at Yale College, of the water of the Bonanza, Deep, and Chamberlin wells, determined that it is very hard, contains carbonates, is unfit for use in boilers or laundry.

There is a fifth well at Weston's mills, near the Deep well bored by Jesse Button, but it is now abandoned. The well has a temperature of 48° for summer and winter.

SOUTH DALTON OR WARNER MOUNTAIN FAULT.

The west end of this fault can be well studied a hundred rods north of where the road from Pittsfield to Washington Station first crosses Sackett Brook, in a narrow gorge running east and west and forming the gathering ground of a small brook, shown on the map, that runs west, crosses the north and south road, and joins Sackett Brook.

The north wall of this narrow valley is composed of the dark Becket gneiss, the south wall of the pure Cheshire quartzite, and they both strike north and south and dip west.

Going west to the next point where Sackett Brook crosses the road, one may take a wood road north from the western house (J. Sweeney's) of the small settlement 100 rods up the mountain side and 100 feet above the main road to a group of logging huts near a bridge.

Five rods up the brook, above this bridge, one finds the white quartzite on the south abutting against the dark Becket tourmaline-bearing gneiss in a well-marked vertical east-west fault, which can be traced in the bluff a long way east to a point where, north of the eastern house of the village (W. Kirschner's), the quartzite begins to come in contact with the older gneiss, and where the junction of the two gneisses is also well exposed a long distance in a steep bluff.

The fault limits the Dalton normal anticline on the south. South of the fault the quartzite extends a mile farther east than on its northern side. All along the roadside, south of the great southward-facing scarp caused by this fault, are numerous great boulders of a coarse quartzite breccia cemented by much limonite—a friction breccia derived from this great fault. (See p. 80.)

At a point a half mile north of the top of Warner Mountain the

¹ This was probably because the fault plane was struck at this point and the tools fell into the cavity, as in the case of the Brown Brothers' well, before mentioned.

corner of the pre-Cambrian area can be clearly mapped in the bare hilltop. From this point east the country is covered, but the formations that come up to it on the north and on the south are so diverse that the prolongation of the fault is certain, and its exact position can not be anywhere far from the line given on the map. It is, however, not certain that it cuts off the pre-Cambrian limestone at the overhead bridge south of Hinsdale village, although this is by far the most probable representation of this badly covered area.

LENOX FAULT.

A half mile south from New Lenox Roaring Brook comes down from the mountain. Following it up 100 rods from the road over the distinctly bedded quartzite, which strikes 45° E. and dips 50° W., increasing near the contact to 60° W., the contact above can be seen in the side of the wood road which follows the brook on the north side, and below in the bank at a fine waterfall. The quartzite is here thick bedded and much contorted, especially a little farther south, and its posture is constant. It is vertically jointed for several feet west from the contact and a few scales of muscovite appear on the foliation faces.

The gneiss rises in a great bluff above the quartzite, and this bluff extends a hundred rods north and several miles south to the East Lee Valley. The gneiss is highly stretched, with strong pitch south. It is much crushed and agrees in type with the Tyringham rock. Many bowlders of the coarse Washington blue-quartz gneiss, blotched with great masses of biotite, have fallen down, and the contact of the two formations is in the bluff above.

A still more interesting exposure of the same contact is found a mile east of Lenox Furnace (fig. 8, p. 44). A wood road runs east from a sharp bend in the main road, and the section shown in the figure begins where this road crosses a brook and continues along its side.

The contorted quartzite at the brook crossing seems to have a rather low dip west, but the finer, flaggy quartzites higher up dip steeply to the west, which seems to be the posture in the beds; flattened pebbles are found higher up. These beds and the thick, granitoid quartzite which follows (and which, as in the Dalton clubhouse section, is characterized by a pale-green muscovite) are full of small tourmalines and connect with the Cambrian.

At the contact, which occurs in a great white ledge south of the brook just before reaching the thick woods, only a rod of a true Becket gneiss intervenes between the micaceous quartzite and the black-and-white pre-Cambrian gneiss. There is a conformity of foliation at the junction, but while the quartzites strike north the older gneisses strike nearly east, and the extent and character of the fault can not be determined. It depends upon the thickness of the gneissoid lower member of the Cambrian, and this is variable; at times the Cambrian seems to be a quartzite to its base.

Five rods east of the contact of the section shown in fig. 9 on page 45, at the point where the road from Lenox Furnace if prolonged east would cut the 1,400 contour line, is the contact of the white-and-black banded Lee gneiss and a stretched gray Tyringham gneiss. The wood road runs over bare rock at this point, and there is, resting unconformably upon the vertical edges of the Lee gneiss, a thin veneering of a dark jointed Cambrian slate containing small pebbles.

The complex series of faults near East Lee can be only partially deciphered, and their connection with the Lee faults is not clear. The matter is discussed under the sections describing the East Lee limestone (p. 50) and the Ferncliff faults (p. 88).

TYRINGHAM FAULT.

The Tyringham fault has had much to do with the formation of the deep Tyringham Valley. How much it has been assisted by the solution of the pre-Cambrian limestones can not be determined.

It brings the pre-Cambrian up against the Cambrian in the mouth of the valley, probably hides north, and is upthrown on the north side. Lower down the valley it has brought Cambrian and pre-Cambrian together, and in its continuation has formed the upper valley of Clam River, as the Otis fault has fixed the upper course of the Farmington River.

INTRUSIVE ROCKS.

Intrusive rocks, both basic and acid, are almost absent from the Becket and Sandisfield quadrangles, except so far as the pre-Cambrian rocks are altered eruptives. West of the great granite stocks which look down on the Connecticut Valley and their broad fringe of dikes, the isolated dike of porphyritic granitite in Middlefield is almost the only acid intrusive which approaches this territory. The greatly altered black massive hornblendic rocks of Becket and of Ball Mountain and vicinity, associated with the Cambrian gneisses in the extreme southwest corner of the area, are the only exception among the basic rocks. The same is true of the extension of this area to the north across the State. Two small, much-altered dikes of basic rock are indicated by Professor Wolff in the Hoosac Mountain map as northeast and southeast of the village of Berkshire, and a third pre-Cambrian dike is described from Oak Hill, on the north border of the area. The same seems also true of Greylock Mountain and of the Taconic Range for a considerable distance to the west. The basic rocks of the Cambrian are described on page 69, in order to compare them with the amphibolites formed from sedimentary beds.

Pegmatite.—A well-characterized graphic granite is represented in Mr. D. Clark's collection, which was obtained from the roadside in West Otis village. The granite 50 rods below Windsor Falls, in Dalton, south of the brook, contains good crystals of orthoclase and a little actinolite in biotite, and is soaked full of a lemon-yellow iron salt due to

change of biotite and actinolite. In the southwest part of the Sandisfield quadrangle small pegmatite veins and impregnations are quite frequent, but not extensive enough for mapping. They present no peculiar characteristics except at the occurrence north of Town Hill, in Sandisfield, where the crushing has sheared the large tourmalines in a remarkable way into a series of echeloned plates. The small pegmatite dikes bordering the amphibolite at the Becket quarry are described on page 75, and those at the West Norfolk cut on page 77.

GLACIAL DEPOSITS.

The whole upland country is covered by drift, often very heavily, especially in the south of Becket and the north of Otis, but presents little of special interest.

POST-GLACIAL DEPOSITS.

The Hoosac limestone valley is continued south over a low pass in Lanesboro into the broader Housatonic Valley at Pittsfield by way of Unkamet Brook. The Hoosac Mountain Range from the north line of the State to the north of Dalton presents so steep and uniform a slope to the west that it forms an unbroken line of division between the Champlain deposits on both sides of the range. When, however, the limestone expands eastward in the center of Dalton a partial union occurs.

This Dalton bay is deep, being underlain by the Stockbridge marble, which is easily removed by erosion. It is, moreover, continued southeast across Hinsdale and Washington by a curious transverse depression in the Berkshire Hills, which, although at a much higher level than the Pittsfield Plain, is yet much below the crest of the ridge. It begins narrow, at its southeast corner, and extends as a broad depression across Hinsdale, where it drains west as the Housatonic, and is continued beyond the Washington station, where it expands into a deep amphitheater and suddenly narrows into a canyon, which continues into Becket and contains the head waters of the Westfield River—a tributary of the Connecticut.

When the boundaries of the complex overthrown Hinsdale anticline were made out, the lowest easily decomposing beds of the pre-Cambrian nucleus of this anticline were seen to have conditioned this depression, which is divided at the Washington station by a dam of the decomposing gneisses about 1,550 feet above the sea. These furnished the barrier which fixed the level of the Hinsdale lake in Glacial time, and which forms the watershed of the present topography.

WASHINGTON BASIN.

As the ice melted up the Westfield River Valley it at last set free the canyon already mentioned, between Becket and Washington stations, and the deep amphitheater into which the canyon expands

just before reaching the latter station. As the waters escaped from the ice and passed through the gorge, they left a great body of sand in the basin, and this at a time which slightly antedated the formation of the Hinsdale lake described below.

For nearly a square mile north of Washington Station the broad, flat-topped sands stand 80 feet above the bottom of the Hinsdale lake. Recent extensive excavations by the railroad along this plain showed that for long distances it is composed of broad, undulating sheets of nearly horizontal sands and gravels, bending down on the south, with delta front structure. They were probably laid down when the ice still occupied most of the Hinsdale Basin to the north and had just begun to send its waters down the newly opened gorge to the south.

HINSDALE LAKE.

A description of the heavy gravel and fine sand deposits which fill the basin back (north) of the Washington sand plain across Hinsdale and which end abruptly in a terrace scarp on the east edge of Dalton, high above the level of the sands in the Pittsfield-Dalton Valley, will be best appreciated if given in the terms of the theory which seems to explain them.

The sands seem to have been deposited while the ice, having just abandoned the Hoosac Range to the east, still filled the limestone valley to a point south of Pittsfield and projected into the Dalton bay, completing the boundary of the lake near the present western boundary of Hinsdale Township, and about a mile north of Hinsdale village.

The Washington gneiss barrier determined the height of the waters, and heavy floods from the north and northwest swept across the ice and into the lake, carrying great masses of sand and gravel which, exactly as in the filling of a mill pond, were deposited in the upper part of this lake, filling the narrow northern portion from the point where the ice stood, across the area where is now the Catholic cemetery, extending southward, and expanding with the widening of the basin to a broadly curved line just south of Hinsdale village.

The great plains to the north and east of the village (the level of Maple street), about 1,520 feet above the sea, are a remnant of this extensive deposit, and the magnificent terrace scarp which starts from the road running southeast from the town library and about 50 rods from that building and runs a half mile east to the next road, is the terrace front of the great delta that was advancing into the lake when a period was put to the lake itself.

On the recession of the ice northward into the Dalton bay, the lake drained, forming the present Housatonic River and cutting away much of the old delta. The sand which had rested against the ice caved to terrace scarp sloping north toward the Dalton bay, traces of which can be seen just north of the Catholic cemetery.

In Hinsdale one must mentally restore the level of Maple street, t.

broad plain east of the village, and carry it across to the hillside on the west of the village, in order to understand the great sand deposit, for brooks and temporary washouts have carried forward the destruction begun by the breaking away of the lake.

From the foot of the great delta front below the library a broad, flat plain of fine sand extends south, the whole width of the basin, to the foot of the transverse sand plain in the Washington Basin which bounds the lake on the south.

The plain descends slightly to the south and the river meanders slowly across its flat surface. The fine sands were being spread over the bottom while the great gravel delta was advancing into the basin and gradually covering them. The high delta flats at Hinsdale and at Washington Station and the lake bottom bed between them can be clearly made out from the contours on the inch-scale map.

DALTON KAMES.

A great kame starts high up on the Wakonah Falls Brook in southwest Windsor. The broad, open valley is in its northern part and for a long way south bottomed by till, and is then suddenly covered by gravels which gain great thickness southwardly before they reach the reservoir 3 miles northeast of Dalton. Southeast of the latter place, in the northwest of Hinsdale, similar sands expand in a broad basin. These join the Windsor sands and extend west down the Wakonah Brook Valley into Dalton as a well-sorted gravel kame of large dimensions (a long sand plain abounding in deep pits) which winds strangely across Dalton and is finally submerged beneath the broad sand stretches which expand westward from the Pittsfield plains.

It is clear that these gravels began to be deposited when the ice still filled the Dalton depression, and that the waters that brought them had then an outlet south across Ashmere reservoir into the Hinsdale lake; that, as the ice lowered, the drainage of West Windsor and North Hinsdale ran southwest across the ice, by Wakonah Brook, into the Housatonic Valley. Later the horizontally stratified gravels were let down by the ice remnants on which they partly rested and sank to such a level that they were in places wholly, and in places only partially, submerged by the sands which were afterwards swept south through the Hoosac Valley and spread on the Pittsfield-Dalton Plain.

HIGH TERRACES IN BECKET.

A high mountain ridge extends northwest from Becket Mountain, and for several miles is flanked by two great terraces, at 2,080 and 2,000 feet, which seem to be the remnants of a glacial lake whose waters finally drained into Basin Pond Brook. These terraces can be reached by the blind road west of the reservoir. They have not been made the subject of special study.

HIGH SANDS AT ENTRANCE TO EAST LEE VALLEY.

Standing on the hill south of Lee and looking across to the entrance of the East Lee Valley one sees that the whole broad mouth of the valley is clogged by exceptionally high, flat-topped sands, which project into the valley in great lobes. They have been notched by the cutting for a railroad that was never finished, and, as usual, have a cemetery on their flat surface. They represent the filling of a temporary lake, held up by the Berkshire Valley ice and drained southeast down the East Lee Valley.

DEFLECTED GLACIAL DRAINAGE DOWN THE HINSDALE, EAST LEE, AND TYRINGHAM VALLEYS.

Each of these long valleys has been greatly affected by the movement of the ice out of the Berkshire Valley, and by the deflection of the flood waters during the meeting of the ice.

From Hinsdale down the Westfield River, from East Lee down the Farmington River, and from Tyringham down the Clam River, this influence is felt the whole length of the valleys and out across the Connecticut Valley in Massachusetts and Connecticut. Boulders of blue-quartz gneiss are not rare here, while the "hardheads" of the Cambrian quartzite from the Housatonic Valley are everywhere very common.

MINERAL RESOURCES.

LIMESTONES.

Pre-Cambrian.—The time has long past when the Hinsdale limestone was burned for quicklime. Most of it is too impure for architectural purposes. The limestone at the mouth of Coles Brook, in which the chondrodite grains have changed to pale yellow-green serpentine, is adapted to ornamental purposes, and the heavy bed, crossed by the Housatonic branch, southwest of Hinsdale is very pure and of even grain, firm and of good luster, and ought to be considered as a source of marble.

Silurian.—The Stockbridge limestone or dolomite is quarried extensively for local uses in the deep bays which penetrate the Hoosac Range in Dalton and Tyringham, and the important quarries south of Lee village have furnished large quantities of high-grade marble, from which the Washington Monument, the Capitol extension, Girard College, the new city hall in Philadelphia, and St. Patrick's Cathedral in New York City were built. It is a white, durable, but rather coarse marble, and cubes 20 feet on a side can be furnished from the quarries. It sustains the highest tests for crushing strength.

Analysis of white dolomite from Lee, Massachusetts.

[G. P. Merrill: Cat. Nat. Mus., 1889, p. 505.]

	Per cent.
Carbonate of lime.....	54.021
Carbonate of magnesia.....	43.932
Oxides, iron and aluminum.....	.365
Loss.....	.610

Tests of strength of dolomite (marble) from Lee, Massachusetts, at Watertown Arsenal.

[G. P. Merrill: Cat. Nat. Mus., 1889, p. 497.]

Size of cube.	Position.	Strength per square inch.	Remarks.
5.91+.....	} End	22.860	{ Sustained maximum load of testing machine without apparent injury.
5.92+.....			
5.92+.....			
5.91+.....	} Bed.....	22.900	Flaked off along one edge.
5.91+.....			
5.90+.....			
5.89+.....	} Bed.....	21.700	Crushed suddenly with report.
6.00+.....			
5.90+.....			
5.9+.....	} End	20.504	Burst into fragments suddenly.
5.91+.....			
5.90+.....			
5.93+.....	} Bed.....	22.370	{ Effect of loading, slight flaking of one face of block; did not break.
5.93+.....			
5.93+.....			
5.92+.....	} End	22.820	{ Sustained maximum load of testing machine without perceptible injury.
5.92+.....			
5.91+.....			

GRANITE.

Pre-Cambrian.—The coarse gneisses of the pre-Cambrian series have been quarried for common work, like bridge building and underpinning, but have been used only locally. They rust badly, and may crumble.

Cambrian.—The conglomerate gneisses are often so strongly metamorphosed that they become complete granites. This seems often to depend on their proximity to sharp upfolding of the pre-Cambrian rocks. The best quarry is that of the Chester Granite Company, in the south-east corner of the Becket quadrangle. This granite is fine-grained and clear gray, a little too dark for polished work but taking a fine surface and furnishing large blocks of even grain and color, suitable for the best monumental work. A similar stone has been much worked in the Clark quarry, beside the railroad west of Coles Brook. Here the passage of the massive quarry stone into the common flaggy gneiss can be clearly seen. A promising quarry has been opened on N. Alderman's land, in the center of Becket, and in Otis the quantity of good granite is inexhaustible. In the south part of the area in New Marlboro and Norfolk a rock of the same age and character has been much quarried, especially on the east slope of Ball Mountain.

FLAGSTONES.

The Cheshire quartzite is mentioned by Hitchcock as furnishing the most perfect flagstones in the State. The best quarries were in the west part of Washington, 5 miles southeast of Pittsfield. Other quarries occur in Tyringham and Lee. Little work, however, seems to be done on these beds now.

BUHRSTONES.

In the same hill in Washington in which the flagstones occur buhrstones were formerly quarried which sold for \$70 to \$80 each. This industry also has passed away.

GLASS SAND.

Where the Cheshire quartzite extends far up into the mountains in Washington much glass sand is dug and carted down to the railroad. In the western part of Washington also and in the Gulf at Dalton much of the quartzite is pure enough for use in glass making.

ROAD MATERIAL.

In Hitchcock's Final Report on the Geology of Massachusetts (p. 211) is perhaps the first suggestion of a rock for road building in the State. The harder varieties of the Cheshire quartzite are thought to be well fitted for this purpose. It will certainly be the best local rock for this use, but the pure quartzite found in the Stockbridge limestone will be nearly as good. The Gulf in Dalton, the country in Washington south of Sackett Brook and east of New Lenox, the western ridge at Fernside in Lee, and the quarry just north of the river, together with the great hill nearly a mile east of Lee, will furnish material in abundance.

SOAPSTONE.

A large amount of soapstone has been taken out at the quarry beside the brook above Wakonah Falls in the south of Windsor, and recently the bed has been opened west of the old quarry and good, soft, slaty soapstone obtained. Along the same bed, a mile southwest, some work has been done on the hard, green, massive chlorite associated with serpentine. A pale-green, fine-grained steatite occurs in large amount as a selvage on the east of the great limestone bed cut by the east branch of the Housatonic in the southeast of Hinsdale. This would form a beautiful rock for inside work.

IRON ORES.

The pre-Cambrian rocks are very rusty, especially in their upper strata, and have everywhere tempted mining. As this rustiness depends largely upon the decomposition of pyrite it is not a good indication of valuable ore. Considerable digging has been done just east of Hinsdale Center, at N. Alderman's in Becket, and at the Hotchkiss and Cleveland mines at New Marlboro. The principal ore is pyrrho-

tite. Nothing has been found to justify expenditure. The Cleveland mine was first opened as a gold mine but latterly has been worked as a nickel mine.

GRAPHITE.

Considerable excavation has been made at the "lead mine" east of Washington Station, on the Lyman place, and openings have been made along the same band at several places to the north and at the creamery near Hinsdale. Graphite occurs in considerable amount on Sky Hill in Tyringham and across New Marlboro, but nowhere in sufficient quantity for mining.

GOLD AND COAL.

The Cleveland mine in New Marlboro was first opened as a gold mine. Buttons of gold and silver *received from the assayers* are shown by the owners. There is no probability that gold in paying quantity will be found within the limits of the area covered by the map. In my notebook are the printed-out answers to the questions of a deaf old man living in the south part of Windsor, the sides of whose house were heaped with great blocks of rock full of rotted yellow mica, which he fondly believed to be gold. The rock had been quarried and brought down by him from the mountain to the east. I tried in vain to persuade him to waste no more labor on the search.

The following items appeared in the Springfield Republican:

1895. Yellow Metal at Hinsdale.—Work of mining gold at the Primrose farm at Hinsdale will begin in the spring. Assays have varied considerably, but all find gold in paying quantities. Ricket and Banks, of New York, have made three fire assays; Professor Suthphen, of Gloversville, New York, has made numerous assays, the last being of sand that yielded \$56.33 per ton. A large syndicate in New York City is trying to buy a part of the Primrose farm. The interested capitalists live in Pittsfield. The Fleming farm, owned by George Duncan, of Middlefield, will soon pass into the hands of a syndicate of Springfield men if proper terms can be made.

August 15, 1896.—George M. French has a number of men excavating on his "gold find" preparatory to the final examination by Professor Suthphen, of Albany. Despite the contradictory statements made by different assayers Mr. French still has some hopes and flattering offers as well. The numerous assays made by reliable authorities do not agree. While some find gold in large quantities, others find little or no trace.

I have not visited the farm since the new mine was opened. My earlier study of all the ledges of the region had not led me to expect important gold deposits there. The following similar account is quoted for the interesting legend and note concerning the custom of selling mineral rights in the hill towns.

Long ago there was mining for gold done in that wild region known as "the Gulf," in Dalton, in a very desultory way, however, without capital and with no thoroughness, and by those not expert in prospecting.

The discoveries at Primrose farm have stimulated explorations and inquiry, with results that are surprising and may be important and profitable. We announced exclusively last week Mr. Duncan's purchase of the Fleming farm, which, it is

believed, contains a continuation of the Primrose "fissure," and the fact that foreign capital was ready to invest upon assay proof of a good outlook. Mr. Corey, in the town of Washington, but near the Primrose, has had assays made from superficial rock contaminated or impregnated from the Primrose, and finds a yield of \$11 to the ton. The William Pease farm, also in Washington, has shown such promise that it has been leased for prospecting and mining purposes by a syndicate from Lee—W. H. Gross, E. Ely, and Mr. Davis, the latter said to be an experienced mine hunter.

That mineral wealth was suspected or believed to exist in these Washington farms is evident from the fact that thirty years ago farms were sold subject to the sellers' reserved right to prospect for and dig minerals. An instance of this is the L. A. Huban farm, owned by father and son, and comprising about 300 acres. This farm adjoins the Pease farm, we believe, leased, as stated, to Gross, Ely, and Davis, and overtures for its purchase by the individual or syndicate for whom Mr. Post is acting were made a good while since. It is only recently, comparatively, that the reservation as to minerals and mining was "bought off" by young Mr. Huban.

There is a legend lingering in the memories of men of Lenox and vicinity that, in the days of legend, an Indian, remnant of a tribe or a descendant of some family of these wandering original Americans, used to tell the white people about a coal deposit he knew of in the woods of Washington. This was before the days of railroads and coal sheds, and when wood was the only and abundant fuel. It is even related that a bottle of "fire water" was offered as a test to prove the assertions, the Indian to have the drink if he brought a pail of coal to Lenox Dale, as he said he could. He was watched, the white man then as now intending to get the best of the Indian, by discovering his secret, but he was too smart for the watchers. He slipped off in the night and returned in the night, bringing the pail of coal. Mr. Huban believes this coal mine is on his farm.

While he was plowing in one of his fields last May he turned up several lumps of coal; a piece of it is now on the Sun's desk. Mr. Huban has owned the place about thirty years, and there has been no such use of coal about the farm as should make its presence probable or even possible. He has done no prospecting, made no examinations to speak of, but is satisfied in his own mind that there is a coal deposit where the outcroppings were struck with the plow.

Of course there is not the slightest possibility of finding coal in Washington, and the prospect of discovering gold in paying quantities is scarcely better. More than fifty years ago President Hitchcock published in his final report a long list of similar legends and foolish searches for gold, in the hope that the tendency to waste money in that direction might be checked with increase of knowledge. I do not, however, find any apparent decrease in the number of "gold mines" in the region.

A MINERAL LEXICON OF EASTERN BERKSHIRE COUNTY, MASSACHUSETTS.

The region covered by this lexicon embraces the towns of Windsor, Dalton, Hinsdale, Becket, Lee, Tyringham, Otis, Sandisfield, and New Marlboro.

An attempt has been made to give a full chronological history of each mineral, its geological age and distribution, and its mineralogical varieties and crystalline form. All sections which are not followed by citations are by the author. The greater portion of the material studied is contained in the collection of Mr. Daniel Clark, of Tyringham, and where it is not otherwise stated it may be assumed that the best illustration of every mineral in the county is to be found there.

ALBITE.

1891. **Albite.** New Marlboro.

A beautiful albite in good crystals a half inch long, showing a fine moon-stone effect in unusually deep blue on the face M (010). It occurs in pre-Cambrian gneiss at the Hotchkiss mine, associated with pyrrhotite and pyroxene. The crystals are limpid and free from inclusions, as seen under the microscope, and the opalescence is due to the cleavage on OP (001). It extinguishes in plates cut parallel to M at $+14^{\circ} 21'$, and is thus an albite.

1895. **Albite replaced by quartz.** Tyringham (Sodom).

Pre-Cambrian. See page 52 for a description and illustration of this remarkable pseudomorph, which retains the twin striation and pearly luster with great perfection.

ALLANITE.

1852. **Gadolinite.** Becket.

C. U. Shepard: Treat. Min., p. 253. This is probably the allanite from the pre-Cambrian gneiss.

1876. **Allanite.** Becket.

C. U. Shepard: Cat. Min. within 50 miles of Amherst, p. 7.

1890. **Allanite.** Becket. Hinsdale. Dalton. Washington. Otis. Tyringham. Sandisfield.

Allanite is everywhere found in scattered crystals of small size in the Washington (pre-Cambrian) gneiss. Its small pitch-black crystals, with dark reddish decomposition borders and the slight puckering of the fracture in the inclosing gneiss which radiates from each crystal, are very characteristic of the rusty pre-Cambrian gneisses. The best localities are on the brook south of the Dalton clubhouse and opposite D. Clark's house in Tyringham.

AMPHIBOLE.

1823. **Asbestos.** Windsor (near Cummington soapstone quarry).
Asbestos adhering to actinolite.
J. Porter: Min. Loc., Am. Jour. Sci., Vol. VII, p. 252.
1824. **Black hornblende.** Washington.
Well crystallized.
J. Porter: Am. Jour. Sci., Vol. VII, p. 253.
1824. **Tremolite.** New Marlboro.
E. Hitchcock: Geol. of a part of Mass., Am. Jour. Sci., Vol. VIII, p. 35.
1824. **Tremolite.** New Marlboro. Pittsfield. Lee.
New Marlboro; Pittsfield; in dolomite, bladed, granular.
Lee; fibrous, fibers more than 2 feet long.
C. Dewey: Geol. Berkshire, Am. Jour. Sci., Vol. VIII, p. 46.
1825. **Tremolite.** Lee.
Above cited.
S. Robinson: Cat. Am. Min., p. 55.
1825. **Tremolite.** New Marlboro.
S. Robinson: Cat. Am. Min., p. 63.
1825. **Actinolite.**
(The article under 1823, above, is cited.)
The actinolite is found in the north part of the town in large, elegant crystals, which are fasciculate, radiate, or intermixed (J. Porter).
S. Robinson: Cat. Am. Min., p. 77.
1825. **Hornblende.** Dalton.
C. A. Lee: Min. Loc., Am. Jour. Sci., Vol. IX, p. 43.
1828. **Hornblende.** Dalton. Becket.
Rock var. slate. East part of Becket, granitic.
Amos Eaton: Geological Nomenclature, Am. Jour. Sci., Vol. XIV, p. 145.
1832. **Hornblende.** Litchfield County, Connecticut. Sheffield and Great Barrington, Massachusetts.
White crystals, more than an inch long and three-fourths of an inch wide but much flattened, abound throughout the dolomite of Litchfield County, Connecticut, particularly at Canaan; they are also found under similar circumstances farther north into the borders of Massachusetts, at Sheffield and at Great Barrington.
C. U. Shepard: Treat. Min., Vol. I, pt. 2, p. 266.
1841. **Tremolite.** Tyringham. Lee.
In dolomite.
E. Hitchcock: Final Rept., 585.
No. 537, Catalogue of State collection, p. 809.
1844. **Actinolite.** (*Augitus proteus*.) Windsor.
J. D. Dana: Sys. Min., 2d ed., p. 439.
1844. **Tremolite.** (*Augitus proteus*.) Lee (east part).
Excellent specimens.
J. D. Dana: Treat. Min., 2d ed., p. 371.
1858. **Tremolite.** Becket (southeast part).
Dolomite with tremolite. E. Hitchcock: No. 187 under limestone in Sixth Ann. Rept. Bd. Agri. Mass., Appendix, p. xxxv. Large masses of loosely aggregated and coarse-bladed tremolite, probably from the south end of the Coles Brook pre-Cambrian limestone.

1868. **Actinolite.** Windsor. Lee.

Specimen from Lee is radiated.

J. D. Dana: Sys. Min., 5th ed., p. 241.

1868. **Tremolite.** Lee (1½ miles southwest of meetinghouse).

Idem, 5th ed., p. 241.

1892. **Actinolite.** Windsor. Lee.

Specimen from Lee is radiated.

J. D. Dana: Sys. Min., 6th ed., p. 1060.

1892. **Tremolite.** Lee.

Cited as in 1868.

J. D. Dana: Sys. Min., 6th ed., p. 397.

1894. **Tremolite.** Lee.

In Stockbridge limestone. In separate blades and in long radiate sheaves. The bladed type was abundant in the old Gross quarry and went down to a great depth, spoiling a large quantity of stone. Specimens are found in every collection.

1895. **Asbestos.** Lee.

In Stockbridge limestone. As felted paper-asbestos in thin white sheets several inches across and as fibrous radiated masses near the Hobbs place in South Lee. D. Clark collection.

1895. **Tremolite.** Tyringham (Sodom, below Hop Brook gorge).

In broad, radiate, columnar masses as large as one's fist, made up of pale greenish gray needles 2 to 3 inches long derived from white pyroxene. Also in finest needles shooting through limpid quartz. Pre-Cambrian. D. Clark collection.

1895. **Tremolite.** Monterey (Bear Mountain).

In pre-Cambrian. Straight, fibrous, pale-green to white asbestos fibers 3 to 4 inches long. D. Clark collection.

1895. **Actinolite.** Tyringham (Hop Brook gorge).

In pre-Cambrian limestone. Black to dark-green actinolite in matted blades grown through orthoclase, and broad parallel-bladed masses several inches in length, making very beautiful specimens. It grows around wernerite and causes the bending of the crystals. D. Clark collection.

1895. **Hornblende.** New Marlboro (on road to Southfield, at deep excavation by roadside, in the very rusty rock).

Pre-Cambrian. Cavities are filled with black hornblende crystals 1½ inches long; bladed, well terminated, simple forms. D. Clark collection.

1895. **Hornblende.** Monterey (Bear Mountain).

Pre-Cambrian. In green, massive hornblende rock, fine, stout, black crystals ∞ P (110), ∞ P ϕ (010), ∞ P ∞ (100), P (111), OP (001).

1895. **Tremolite.** Tyringham (the Cobble).

Fine, radiating snow-white tremolite in the Stockbridge limestone at the foot of the mountain. D. Clark collection.

1895. **Hornblende.** Tyringham (the Cobble).

Pre-Cambrian. Fine jet-black crystals in the garnet biotite rock, with ilmenite above the limestone. D. Clark collection.

1896. **Actinolite.** Becket (one hundred rods east of R. Alderman and son's house).

In the Hinsdale (pre-Cambrian) limestone in large, pale-green, compact masses and in loosely interwoven aggregates of coarse blades of rich green color shading to brown.

1896. **Actinolite.** Otis.

The coarse pre-Cambrian limestone at Otis Center contains an emerald-green bladed actinolite with scapolite.

1896. **Hornblende.**

A black fibrous hornblende is an abundant constituent of the Lee gneiss (p. 33), and of the amphibolites which occur in the Becket gneiss.

APATITE.

1841. **Phosphate of lime.** Hinsdale.

In mica-schist. E. Hitchcock: Final Report of Geol. of Mass., p. 604.

1844. **Apatite.** (*Fluellus hexagonus*.) Hinsdale.

J. D. Dana: Sys. Min., p. 238.

1868. **Apatite.** Hinsdale.

Sparingly. Idem, 5th ed., p. 553.

1892. **Apatite.** Hinsdale.

Idem, 6th ed., p. 767. This locality can not be recovered.

1895. **Apatite.** Tyringham (Sodom, below Hop Brook gorge.)

In pale-green hexagonal prisms half an inch long in white orthoclase, from the Hinsdale (pre-Cambrian) limestone. D. Clark collection.

ARAGONITE.

1895. **Aragonite.** New Marlboro (road to Southfield, at a deep cut in rusty rock by roadside).

In pre-Cambrian rocks, but of late formation. In fine tufted masses of yellow crystalline blades and needles. D. Clark collection.

BARITE.

1890. **Barite.** Becket (east of Shaw Pond).

Boulders from the Hinsdale (pre-Cambrian) limestone, with galena and chalcopyrite. In bladed masses.

BERYL.

It is remarkable that there is no beryl in Berkshire.

BIOTITE.

1895. **Biotite.** Tyringham (the Cobble).

Broad wrinkled sheets of black biotite 2 to 3 inches across, probably pre-Cambrian, from Sky Hill above the Cobble. D. Clark collection.

1895. **Biotite.** Tyringham (Hop Brook gorge).

In pre-Cambrian rocks. Magnificent crystals were obtained by Mr. Clark from the rotten zeolite vein in the limestone; great perfect crystals, with polished faces, hexagons 5 inches by $4\frac{1}{2}$ inches and 3 inches thick. Other crystals were tapering, 3 inches at the base and $1\frac{1}{2}$ inches high. Very many other great crystals were compressed at the edges, often regularly at all the edges, into perfect saucers. The faces of the vertical zone were often coated by a thick layer of the white, velvety, globular sphærostitbite, forming specimens of great beauty. Smaller prisms, often an inch in length, grow out from the larger ones. A strongly developed parting often divides the great crystals into long prismatic forms. Many crystals had fallen in the cavities, where they formed and are cemented by the sphærostitbite. Many have changed to jefferisite, q. v.

CALCITE.

1814. **Elastic marble.** Pittsfield.

"On taking up one of these stones, from a quarry near Pittsfield, which was just prepared for a gravestone, about 4 feet high and 2 feet wide, I was much surprised at the tremulous motion which I perceived." It bent with the least pressure, but recovered itself without the smallest change or crack. Only a few specimens were elastic. They were grayish white, foliated, granular, and effervescent.

W. Meade: Mineralogical notice respecting elastic marble from Massachusetts.

A. Bruce: Am. Min. Jour., Vol. I, p. 93.

1814. **Elastic marble.**

A polished slab 2 feet long and 1 inch thick, dried near the fire, lost its elasticity, which was immediately restored by wetting. Wm. Meade: letter.

Am. Min. Jour., Vol. I, p. 267.

1832. **Limestone.** New Marlboro.

Gray, CaCO_3 , 98 per cent; residue, chiefly mica, 2 per cent marble. Abundant; production cited from Dewey. Mill for sawing in New Marlboro.

E. Hitchcock: Geol. Mass., Am. Jour. Sci., Vol. XXII, pp. 26, 38.

1895. **Calcite.** Lee.

In Stockbridge limestone. In a rare geode cavity and perched upon fine dolomite rhombs (see under Dolomite), is a beautiful crystal half an inch long, having the faces R (10 $\bar{1}$ 1), rounded by $\frac{1}{2}$ R² (21 $\bar{3}$ 4) and $-\frac{1}{2}$ R (0112), R (10 $\bar{1}$ 0), R² (32 $\bar{5}$ 1), R³ (2131).

D. Clark collection.

1895. **Marble.** Tyringham.

Boulders. White marble, gray banded marble, black faulted marble.

D. Clark collection.

1895. **Stalactite.** Tyringham (the Cobble).

In the Stockbridge limestone

D. Clark collection.

1895. **Calcite.** Tyringham (Hop Brook).

Pre-Cambrian; very coarse crystalline vein stones, fine gray, pink, plum color, and white; shot through with hornblende crystals, crusted with limpid calcite crystals ∞ R (10 $\bar{1}$ 0), $-\frac{1}{2}$ R (01 $\bar{1}$ 2), 4R (40 $\bar{1}$ 1).

CHABASITE.

1895. **Chabasite.** Tyringham (Hop Brook gorge).

In pre-Cambrian limestone. Massive and in rhombohedra R (10 $\bar{1}$ 1), $-\frac{1}{2}$ R (01 $\bar{1}$ 2), with polished faces 5 mm. across. Green actinolite is intergrown with it. Twins; twinning plane=R. Nearly opaque white.

D. Clark collection.

CHALCOPYRITE.

1890. **Chalcopyrite.** Becket (east of Shaw Pond).

In boulders from pre-Cambrian limestone with galena and barite.

1893. **Chalcopyrite.** Becket (east of Center Pond on farm of M. J. Alderman).

Vein worked 1 inch wide. Associated with pyrite, pyrrhotite, and calcite in hornblendic gneiss of pre-Cambrian age.

CHONDRODITE.

1841. **Augite.** Lee.

"Within 2 miles of Lee we meet with limestone which often contains a mixture of augite, and this mineral being decomposed at the surface yet projecting beyond the limestone the whole rock exhibits a brown, very irregular aspect."

E. Hitchcock: Final Rept., p. 627.

1885. **Chondrodite.** Hinsdale. Monterey.

Noted as occurring in limestone at the Hinsdale railroad station and in boulders between South Lee and Monterey.

J. D. Dana: Am. Jour. Sci., Vol. XXIX, p. 204.

1887. **Chondrodite.** Hinsdale. Lee.

Hinsdale; in village (on railroad) and southwest of the village, west of the railroad.

East Lee; on the high hill between the two valleys coming in from the east, in masses as large as one's fist; also on the opposite side of the valley to the northwest, and in the bottom of the valley a mile east of East Lee.

J. D. Dana: Am. Jour. Sci., Vol. XXXIII, pp. 275, 276.

1892. **Chondrodite.** Lee.

In crystalline limestone in East Lee.

J. D. Dana: Sys. Min., 6th ed., pp. 1059, 541.

1895. **Chondrodite.** Becket. Middlefield.

100 rods east of R. Alderman and son's house, in Becket Center, in a Hinsdale pre-Cambrian limestone band 5 rods wide.

It occurs in red grains, and is especially abundant in a large boulder 100 rods northeast of the ledge. Also in Coles Brook, across Becket and Middlefield, especially at the cut at the mouth of Coles Brook, where it is changed to pale-yellow serpentine.

1895. **Chondrodite.** Hinsdale. Tyringham. Lee.

In especially large masses, of dark red color, partly changed to chlorite at O. Bill's, by the roadside, a half mile north of Muddy Pond, in Hinsdale, and on the high, bare hill east of the hotel at East Lee.

CLINOCHLORE.

1895. **Clinochlore.** Tyringham. Great Barrington.

On Bear Mountain, in matted scales half an inch across, with garnet on a fine-grained biotite-gneiss of pre-Cambrian age.

CYANITE.

1896. **Cyanite.** Becket.

Gray blades, containing small, regular garnets, centrally filled with dark grains, and changing to muscovite. See Pl. I, p. 26.

DOLOMITE.

1821. **Dolomite.** Lee.

Is fetid. Most of that called limestone in the county is dolomite.

C. Dewey: Am. Jour. Sci., Vol. III, p. 239.

1824. **Dolomite.** Lee. Pittsfield. New Marlboro.

In latter place contains augite as well as tremolite.

C. Dewey: Geol. Berkshire, Am. Jour. Sci., Vol. VIII, p. 35.

1825. Dolomite. New Marlboro.

With augite and tremolite.

E. Hitchcock: *Geol. of part of Mass., Am. Jour. Sci., Vol. VIII, p. 35.*
S. Robinson, *Cat. Am. Min., pp. 55, 63.*

1854. Dolomite with tremolite. Becket (southeast part).

E. Hitchcock: *Sixth Ann. Rept. Mass. Bd. Agri., Appendix, p. xxxv, No. 187.*

Contains much rather fine-bladed tremolite; is probably from a boulder of the Stockbridge limestone.

1876. Dolomite. Hinsdale. Lee. Lenox. Stockbridge.

C. U. Shepard: *Cat. Min. found within 50 miles of Amherst, p. 3.*

1895. Dolomite. Lee.

In a large drusy cavity from the quarry in the village, in Stockbridge limestone. Rhombs up to an inch on a side, and in other cavities up to 3 inches. Perfectly limpid, and with polished and perfect faces, piled loosely on each other. Some of the rhombs are expanded to broad, flat plates. In others are phantom crystals, containing eccentric, smoky kernels; that is, on a smoky translucent rhomb, half an inch across, is a regular transparent increment two-sixteenths to three-sixteenths inch thick, which is applied only to the three faces adjacent to a lateral solid angle. A complex rhombohedral crystal of calcite half an inch long (see under Calcite) is perched upon one of the rhombs, making a cabinet specimen of rare beauty.

D. Clark collection.

EPIDOTE.**1825. Epidote.** Windsor.

In prismatic crystals in quartz, also granular in hornblende rocks (H. M. Wells).

S. Robinson: *Cat. Am. Min., p. 77.*

1825. Epidote. Dalton.

C. A. Lee: *Min. Loc., Am. Jour. Sci., Vol. IX, p. 43.*

1841. Epidote. Hinsdale.

In mica-schist.

E. Hitchcock: *Final Rept., p. 606.*

1895. Epidote.

Epidote is everywhere a characteristic constituent of the Hinsdale gneiss, but it rarely occurs in sufficient quantities and depth of color to form cabinet specimens. The best place to find it in any quantity is in the river, behind the stone mill in Dalton.

FIBROLITE.**1824. Fibrolite?** Becket (Becket).

Minute fibers, dark, hard, infusible, rare.

C. Dewey: *Geol. Berkshire, Am. Jour. Sci., Vol. VIII, p. 40.*

1825. Fibrolite.

Cited in Robinson's Catalogue. (I have found no fibrolite in Becket.)

1892. Fibrolite. Norfolk, Connecticut.

On Tobey Hill and in boulders to the south, nodules of feldspar and quartz more or less changed to muscovite and fibrolite. Thin section described mica arranged in twinning planes of feldspar.

Wm. H. Hobbs: *Pseudomorphs after feldspar, Am. Geologist, Vol. X, p. 46.*

1895. **Fibrolite.** Otis. Sandisfield.

Commencing with Filley Mountain in Otis, fibrolite becomes gradually an important constituent of the pre-Cambrian gneiss across Sandisfield and into Connecticut.

1897. **Fibrolite.** New Marlboro. Norfolk, Connecticut.

The nodular gneiss that extends from Campbell Falls in New Marlboro to Norfolk Center contains abundant fibrolite in the muscovite nodules.

GADOLINITE.

1852. **Gadolinite.** Becket.

C. U. Shepard: Treat. Min., p. 253.

See Allanite.

GALENA.

1896. **Galena.** Becket (east of Shaw Pond).

In bowlders from pre-Cambrian limestone, with barite and chalcopyrite.

GARNET.

1858. **Pyrope.** Sandisfield.

E. Hitchcock: Cat. State Coll., Mass. Agri. Rept., p. 52, No. 161. (Is a common iron garnet in Tyringham gneiss.)

1895. **Garnet.** Tyringham (pasture of Riverside Farm).

In white mica-schist of Cambrian age, forms ∞ O (110), 202 (112), rich red-brown. Also on the Cobble in deep red crystals an inch across in biotite.

D. Clark collection.

1895. **Garnet.** Monterey (Bear Mountain).

In coarse, white, shining hydromica-schist. Red crystals nearly three-fourths inch across ∞ P (110).

GRAPHITE.

1823. **Graphite.** Hinsdale.

J. Porter: Am. Jour. Sci., Vol. VI, p. 248.

1824. **Graphite.** Hinsdale.

Foliated and granular with augite, nearly slaty, in considerable quantity.

C. Dewey: Geol. western Mass., Am. Jour. Sci., Vol. VIII, p. 54.

1824. **Graphite (black lead).** Hinsdale.

With augite, foliated and massive.

C. Dewey: Hist. Berkshire County, p. 197.

1825. **Graphite.**

S. Robinson: Cat. Am. Min., p. 54.

1825. **Graphite.** New Marlboro.

In great abundance.

C. A. Lee: Min. Loc., Am. Jour. Sci., Vol. IX, p. 43.

1825. **Graphite.** New Marlboro.

E. Hitchcock: Geol. of part of Mass., Am. Jour. Sci., Vol. VIII, p. 54.

1825. **Graphite.**

Above cited. S. Robinson: Cat. Am. Min., p. 63.

1832. Graphite. Hinsdale.

E. Hitchcock: Geol. Mass., Am. Jour. Sci., Vol. XXII, p. 47.

1833. Graphite. Hinsdale. New Marlboro.

E. Hitchcock: Rept. Geol. Mass., p. 395.

1841. Graphite. New Marlboro. Hinsdale. Washington (1 mile north-east of deep cut at summit level—Lyman's opening).

E. Hitchcock: Final Rept., p. 240.

1844. Graphite (*Plumbago scriptoria*). Washington.

J. D. Dana: Sys. Min., 2d ed., p. 539.

1868. Graphite.

Idem, 5th ed., p. 770.

1892. Graphite.

Idem, 6th ed., p. 1060.

1895. Graphite. Monterey (Bear Mountain).

In pre-Cambrian rock. In large masses on top of Sky Hill, with tremolite in blue-quartz gneiss.

D. Clark collection.

1897. Graphite. Hinsdale.

The mineral is everywhere characteristic of the pre-Cambrian gneiss, and openings for mining have been made at three places in the town near the creamery, east of the center; near A. Walkin's house, in coarse salite rock; and in an extensive opening at the mine on the Lyman place above Muddy Pond, east of Washington Station.

HEMATITE.**1890. Hematite. Hinsdale.**

In masses of imperfect flat crystals associated with fine quartz crystals. Min. Coll. of E. B. Underhill, Hallock Mills, N. Y. Presented to Amherst College, 1888.

1895. Micaceous iron. Dalton.

In Cambrian quartzite. An aggregate of warped plates in white quartz. D. Clark collection.

HEULANDITE.**1895. Heulandite. Tyringham (Hop Brook).**

Crystals 1 mm. long, implanted on hornblende and showing the faces $\infty P_{\infty} (010)$, $-2 R_{\infty} (201)$, $OP (001)$. D. Clark collection.

ILMENITE.**1895. Ilmenite. Tyringham (the Cobble).**

Abundant in broad plates an inch square in a quartz vein in a biotite garnet rock; also in other quartz veins 2 inches square one-fourth inch thick, in twisted plates; also in a mass from the drift, part of a large crystal 1 inch thick and 4 inches square.

D. Clark collection.

1897. Ilmenite. Dalton (Day Mountain).

In a lens of coarse granular orthoclase in a muscovite-gneiss full of needles of black tourmaline. It occurs in broad curved lamellæ half an inch thick. Collected by Mr. B. F. Newell, of Dalton.

JEFFERISITE.

1895. **Jefferisite.** Tyringham (Hop Brook gorge).

The great crystals of black biotite at times change to a pale-yellow jefferisite.

D. Clark collection.

LAUMONTITE.

1895. **Laumontite.** Tyringham (Hop Brook).

White square prisms, 20 mm. long, 3 mm. across, and truncated by the usual oblique face. Abundant, but changing easily.

D. Clark collection.

LIMONITE.

1822. **Compact brown oxide of iron.** Dalton.

Incrusting rocks.

P. Cleaveland: Min., p. 607.

1824. **Fibrous brown hematite.** Hinsdale (southwest of town and 4 miles from Pittsfield).

Cement of conglomerate, often half an inch thick.

C. Dewey: Geol. western Mass., Am. Jour. Sci., Vol. VIII, p. 18.

1825. **Fibrous brown hematite.**

Above cited.

S. Robinson: Cat. Am. Min., p. 54.

1825. **Limonite.**

Article cited under 1822.

S. Robinson: Cat. Am. Min., p. 47.

1825. **Iron, compact brown oxide.** Pittsfield.

Breccia, with cement of brown oxide, hematite, and carburet of iron. Interstices lined with minute quartz crystals.

C. A. Lee: Min. Loc., Am. Jour. Sci., Vol. IX, p. 43.

The origin of these limonites cementing the Cambrian breccias is given on page 80.

1828. **Hematite.** Dalton (3 miles south of village).

A. Eaton: Geol. Nomenclature, Am. Jour. Sci., Vol. XIV, p. 150.

1830. **Hematite.** Dalton (3 miles south of village).

A. Eaton: Geological Text Book, p. 34.

1832. **Limonite.** Hinsdale.

At Hinsdale the fibrous variety occurs as a cement to a fragmentary quartz rock.

C. U. Shepard: Treat. Min., Vol. II, pt. 1, p. 15.

1838. **Hematite iron ore (limonite).** Tyringham.

Several hundred tons dug in south part of the town.

E. Hitchcock: Econ. Geol., p. 126.

1841. **Brown hematite.** Tyringham.

Several hundred tons said to have been dug in the south part of the town. Indications of extensive beds.

E. Hitchcock: Final Rept., p. 197.

1844. **Brown iron ore (*Siderus hæmaticus*).** Hinsdale.

Cement in quartz rock.

J. D. Dana: Sys. Min., 2d ed., p. 449.

1852. Limonite. Hinsdale.

At Hinsdale the fibrous variety occurs as a cement to a fragmentary quartz rock.

C. U. Shepard: Treat. Min., p. 277.

1868. Limonite.

Idem, 5th ed., p. 173.

1892. Limonite.

Idem, 6th ed., p. 1059.

Cited only in locality list.

MAGNETITE.**1825. Magnetic oxide of iron. Windsor.**

In octahedra (J. Porter).

S. Robinson: Cat. Am. Min., p. 77.

1841. Magnetic oxide. Tyringham.

Vein 4 inches wide in quartz rock on Bear Mountain, near the road to Beartown.

E. Hitchcock: Final Rept., p. 194.

1895. Magnetite. Tyringham (the Cobble).

In white Cambrian gneiss, in imperfect crystals an inch across.

D. Clark collection.

MELANTERITE.**1824. Sulphate of iron. Tyringham.**

In loose earth near Shaker Village.

C. Dewey: Hist. Berkshire County, p. 196.

MICROCLINE.**1895. Microcline. Tyringham (south side of Hop Brook Valley).**

Large cleavage pieces of flesh color, with fine perthitic banding of albite.

D. Clark collection.

MUSCOVITE.**1822. Mica. Hinsdale.**

It occurs green (J. Porter).

P. Cleaveland: Min., Vol. II., p. 777.

1822. Prismatic mica. Hinsdale.

On the edges of common mica.

C. Dewey: Am. Jour. Sci., Vol. V., p. 399.

1825. Prismatic mica.

Above cited.

S. Robinson: Cat. Am. Min., p. 53.

1895. Muscovite. Tyringham (the Cobble).

In good crystals.

D. Clark collection.

NATRON.**1824. Carbonate of soda. Pittsfield (in springs).**

C. Dewey: Geol. of part of Mass., Am. Jour. Sci., Vol. XIV, p. 32.

1825. Carbonate of soda.

Above cited.

S. Robinson: Cat. Am. Min., p. 65.

Bull. 159—8

OLIGOCLASE.

1895. **Oligoclase.** Monterey (Bear Mountain).

Starting from a point east of Fernside and going south half a mile up the side of Sky Hill. The crystals occur in a green, massive hornblende rock. They are an inch long, of cubical habit and dark flesh color, and show the faces ∞P_{∞} (010), $\infty P'(1\bar{1}0)$, $\infty P'(110)$, $\infty P^3(130)$, $\infty P^3(1\bar{3}0)$, $P_1(\bar{1}10)$, $P_1(1\bar{1}1)$, $2P_{\infty}(201)$, $\frac{1}{2}P_{\infty}(201)$, $P_{\infty}(101)$, $2P_1(2\bar{2}1)$. They show a fine striation over all the faces in the zone of b ; there is a beautiful blue play of color on ∞P_{∞} , like Friedrichsävärn oligoclase.

ORTHOCLASE.

1832. **Feldspar.** Middlefield. Becket.

The crystals are often deeply embedded in calcareous spar.
C. U. Shepard: Treat. Min., Vol. I, pt. 2, p. 203.

1895. **Orthoclase.** Becket (100 rods east of R. Alderman and son's).

In pre-Cambrian limestone. In stout opaque-white crystals up to an inch long, some elongate in the direction of the prism and terminated by $O(001)$ and $P_{\infty}(101)$, and some having $O(001)$ and $\infty P_{\infty}(010)$, forming a square prism terminated by $\infty P(110)$ and $P_{\infty}(101)$. Shows a fine blue opalescence. The same property appears in the feldspar of the coarse granitoid rock adjoining the limestone at the Coles Brook cutting.

1895. **Orthoclase.** Tyringham (John Winthrop pasture, south side upper Tyringham Valley).

From the pre-Cambrian. A white orthoclase, in good crystals of simple form with pyroxene.
D. Clark collection.

1895. **Orthoclase, var. loxoclase.** Tyringham (one-fourth mile southwest of D. Clark's).

In red-brown forms, resembling those from Hammond, New York. Pre-Cambrian, associated with pyroxene.
D. Clark collection.

1895. **Orthoclase.** Tyringham (Hop Brook gorge).

In pre-Cambrian rocks. Greatly etched crystals in chesterlite form.
D. Clark collection.

1895. **Orthoclase.** Tyringham (Sodom, foot of Long Mountain and Hop Brook gorge).

Drusy surfaces of small crystals, often with limpid ends and rounded faces, also in opaque, well-formed crystals $\infty P(110)$, $OP(001)$, $P_{\infty}(101)$, $2P_{\infty}(201)$. Shows fine blue opalescence. Is associated with black, bladed hornblende in Hop Brook, and with white pyroxene and tremolite at the other localities, and is often full of square cavities, from which wernerite crystals have been removed. Pre-Cambrian.

D. Clark collection.

1895. **Orthoclase.** New Marlboro (road to Southfield, at digging in rusty rock by roadside).

Pre-Cambrian. Many fine crystals an inch long, of simple exterior forms $\infty P(110)$, $\infty P_{\infty}(010)$, $P_{\infty}(101)$, $2P_{\infty}(201)$, $\infty P^3(210)$, $P(1\bar{1}1)$; fine blue opalescence; color, opaque-white.

OPAL.

1825. **Opal, hyalite, cacholong, siliceous sinter.** Dalton.

In masses of hornstone.

C. A. Lee: Min. Loc., Am. Jour. Sci., Vol. IX, p. 43.

1890. **Opal.** Sheffield.

Common opal.

G. F. Kunz: Gems and Precious Stones of the United States.

PHLOGOPITE.

1895. **Phlogopite.** Tyringham (Hop Brook).

In many small crystals in wernerite. In pre-Cambrian limestone.

D. Clark collection.

PYRITE.

1824. **Pyrite.** Lee.

In compact masses.

C. Dewey: Geol. Berkshire, Am. Jour. Sci., Vol. VIII, p. 55.

1825. **Pyrite.**

Above cited.

S. Robinson: Cat. Am. Min., p. 55.

1895. **Pyrite.** Tyringham.

One-fourth mile southwest of Mr. D. Clark's house, at the head of the Tyringham Valley. In vein quartz of pre-Cambrian age. In fine crystals one-fourth inch across, superficially changed to limonite O (111),

$$\left[\begin{smallmatrix} 2 & 0 & \infty \\ & 2 & \end{smallmatrix} \right] \pi (210).$$

D. Clark collection.

Also in boulders in village 50 rods west of post-office perfect crystals changing to limonite in a quartz rock full of dolomite, 2 to 3 mm. long

$\infty O \infty (001)$, $\left[\begin{smallmatrix} 2 & 0 & \infty \\ & 2 & \end{smallmatrix} \right] \pi (210)$. Also at Sodom, below Hop Brook gorge, in finely polished crystals 1 to 15 mm. across changed to limonite.

D. Clark collection.

PYROLUSITE.

1825. **Manganese.** Pittsfield.

The compact brown oxide, in considerable quantities.

C. A. Lee: Min. Loc., Am. Jour. Sci., Vol. IX, p. 42.

1895. **Dendrite.** Tyringham (in gorge above Riverside farm).

Beautiful forms in Cambrian quartzite. As they are in the red and black colors, they are in large part iron oxides.

D. Clark collection.

1895. **Pyrolusite.** Monterey (near Bidwell place).

Wavy plumose forms in yellow jasper.

D. Clark collection.

1895. **Dendrite.** Dalton.

Boulder in white Cheshire quartzite.

PYROXENE.

1824. **Ancite.** New Marlboro.

Rough white crystals in limestone (doubtless white pyroxene).

C. Dewey: Hist. Berkshire, p. 194.

(Manifest misprint for augite.)

1824. **Augite.** Hinsdale.

With graphite.

C. Dewey: Hist. Berkshire, p. 197.

1824. **Augite.** New Marlboro. Hinsdale.

New Marlboro; white four, six, and eight-sided prisms. Hinsdale; with plumbago, greenish gray, brown, yellowish, in crystalline forms.

C. Dewey: Geol. Berkshire, Am. Jour. Sci., Vol. VIII, p. 47.

1824. **Augite.** Hinsdale.

With graphite, as at Ticonderoga.

C. Dewey: Geol. western Mass., Am. Jour. Sci., Vol. VIII, p. 48.

1825. **Augite.**

Same cited.

S. Robinson: Cat. Am. Min., p. 54.

1825. **Augite.** Pittsfield. Dalton. New Marlboro.

Principally massive.

C. A. Lee: Min. Loc., Am. Jour. Sci., Vol. IX, p. 43.

1825. **Augite.** New Marlboro

E. Hitchcock: Geol. part of Mass., Am. Jour. Sci., Vol. VIII, p. 35.

1825. **Augite.**

Above cited.

S. Robinson: Cat. Am. Min., p. 63.

1841. **Augite.** New Marlboro. Tyringham.

New Marlboro; green augite in dolomite. Tyringham; white augite in dolomite.

No. 236 Catalogue, p. 809.

E. Hitchcock: Final Rept., p. 569.

1844. **Pyroxene.** (*Augitus diatomus*.) Tyringham.

Cited only under localities.

J. D. Dana: Sys. Min., 2d ed., p. 539.

1852. **Scapolite.**

The canaanite of Hitchcock (from Canaan, Conn.), which is an exceedingly tough, compact, grayish white mineral, and contains sil. 53.36, perox. iron 4.09, alum 10.38, lime 25.80, mag. 1.62, carb. acid 4.0 (99.67)

C. U. Shepard: Treat. Min., p. 178.

1852. **Scapolite.** (Canaanite.) Canaan, Conn.SiO₂ 53.36, FeO 4.09, Al₂O₃ 10.38, CaO 25.80, MgO 1.62, CO₂ 4, 99.67.

Analysis by S. L. Dana.

C. U. Shepard: Treat. Min., p. 178.

1868. **Pyroxene.**

J. D. Dana: Sys. Min., 5th ed., p. 770.

1885. **Pyroxene.** Tyringham.

A white, compact, fibrous pyroxene from Tyringham made a curious white cat's eye.

G. F. Kunz: Precious stones, Mineral Resources U. S. 1883-84, p. 728.

1892. **Pyroxene.**

J. D. Dana: Sys. Min., 6th ed., p. 1059.

1895. **Salite.** Tyringham (on the south side of the valley, a half mile above Clark's).

Large prisms of pale salite, coated, and their interspaces filled with pale-green actinolite, on which are stout, curious quartz crystals, which include

actinolite. They (the quartz crystals) have wavy and rounded faces, and terminate by two or three pyramids.

D. Clark collection.

1895. **Pyroxene.** Tyingham (D. Clark farm).

Boulders of Stockbridge limestone. The mass contained in great numbers doubly terminated crystals of white pyroxene uniformly 1 inch long, half an inch wide, and considerably flattened by the great development of the orthopinacoid. It has the forms ∞P_{∞} (100), ∞P (110), $+P$ (111), $-P$ (111).

D. Clark collection.

1895. **Pyroxene.** Lee (Upper Goose Pond, near Elwells Rocks).

Pale-green pyroxene in stout crystals with perfect basal parting, 1 inch long, three-fourths inch across.

1895. **Pyroxene.** New Marlboro (road to Southfield, in deep digging in rusty rock by roadside).

Pre-Cambrian. Green crystals an inch square, much cracked and corroded.

D. Clark collection.

1895. **Pyroxene changing into hornblende.** Tyingham (foot of Long Mountain).

Pre-Cambrian. Coarse square prisms an inch across and 2 to 3 inches long, of pale-green pyroxene, project outwardly from the limestone, and green bladed actinolite grows from it so as to spoil the surfaces of the pyroxene.

D. Clark collection.

1895. **Pyroxene passing into tremolite.** Tyingham (a half mile southeast of D. Clark's).

Pre Cambrian. In the same way as above described the whitish green pyroxene prisms appear here corroded and separated into distinct cubical blocks, which are much displaced, and out from the whole surface of the prism grew groups of radiate sheaf-like masses of tremolite, with needles often bent. A secondary green pyroxene, having a broad OP (001) face with $-P$ (111) and a second prism, is also developed at this locality.

D. Clark collection.

1895. **Pyroxene.** Tyingham (Hop Brook gorge).

Pre-Cambrian. Deep emerald-green transparent prisms, with perfect basal parting and poor prismatic cleavage. Many twins, twinning parallel to ∞P_{∞} (100) and reaching 4 inches in length. Other crystals are bluish green and pale green. The following combinations occur:

∞P (110), $-P\bar{\infty}$ (101), OP (001).

∞P (110), $-P\bar{\infty}$ (101), OP (001), $P\bar{\infty}$ (101).

∞P (110), $-P\bar{\infty}$ (101), $P\bar{\infty}$ (101), $+P$ (111), $-P$ (111), $2P$ (221), OP (001).

Minute, long, square prisms occur in greasy wernerite. Other crystals occur with the first combination above; stout crystals an inch broad and 2 inches long, deep green, with dull etched surface.

D. Clark collection.

1895. **Salite.** Tyingham (Sodom, below Hop Brook gorge).

The finest salite prisms of dull white color and an inch across and 2 to 4 inches long. The base occurs implanted in black, white, and pink quartz, distantly or thickly scattered. They show the perfect basal parting. Often the prisms have been dissolved and the etched fragments sometimes remain in the square cavities in the black quartz, and blades of white tremolite tapestry the walls as if they had been formed from

the dissolved pyroxene. The pyroxene had often been broken and recemented by quartz, so that the cavities had cross partitions of quartz like the tabulae of a rugose coral. These quartz masses, from which the pyroxene has disappeared, were called by the early geologists mortised rock and thought to be the work of Indians. In the gorge itself occur stout columnar masses of crystals an inch across, which are as large as one's fist. The quartz is pseudomorph after albite. See Pls. II, III, p. 52.

D. Clark collection.

1895. Salite. Otis Center.

Bowlder. Coarsely cleaving, with cleavage surfaces several inches across; pale-green to white color.

1895. Pyroxene. Becket (100 rods east of R. Alderman's).

In pre-Cambrian limestone in large masses of pale-green, massive, coarse pyroxene rock and in loose aggregates of stout eight-sided prisms with strong prismatic and basal cleavage.

1896. Augite. New Marlboro (Cleveland mine).

W. H. Hobbs describes and figures a light-green hornblende which is surrounded and intergrown by a colorless pyroxene ("augite"), the two being orientated. *Science*, Vol. XX, p. 516.

PYRRHOTITE.

1895. Pyrrhotite in crystals. New Marlboro (Hotchkiss and Cleveland mines).

Hotchkiss mine; often an inch long; tapering hexagonal prisms with basal planes. Massive at the Cleveland mine.

1896. Pyrrhotite. Becket (M. J. Alderman's place).

In large masses from pre-Cambrian limestone.

1897. Pyrrhotite. Dalton (limestone locality on brook south of clubhouse on Day Mountain).

Collected by B. F. Newell.

QUARTZ.

1822. Granular quartz. Hinsdale.

It is said to occur in large friable masses, snow white and much resembling sugar. It may prove important in the manufacture of glass and stoneware.

P. Cleveland: *Min.*, Vol. I, 239. Refers to great bowlders of Cheshire quartzite. Cited 1825 by S. Robinson: *Cat. Am. Min.*, p. 53.

1824. Quartz. Lenox. Lee. Hinsdale. Pittsfield. Washington.

Flattened terminated prisms; in quarry at Lenox.

Granular or as sand; everywhere. Yellow and red; Pittsfield, a considerable rock composed almost entirely of small crystals. Chalcedony, yellowish hornstone, cacholong, and opal; Hinsdale. Buhstone; Washington.

C. Dewey: *Geol. Berkshire*, *Am. Jour. Sci.*, Vol. VIII, p. 38. Cited 1825 by S. Robinson: *Cat. Am. Min.*, p. 55.

1824. Blue quartz, fetid quartz, hornstone. Lenox. Pittsfield.

Ferruginous quartz, massive and well crystallized, Lenox. Hornstone, jasper, generally gray and blue, Pittsfield.

J. Porter: *Min. Loc.*, *Am. Jour. Sci.*, Vol. VII, p. 252.

1824. Cacholong, hornstone, chalcedony. Hinsdale.

C. Dewey: *Geol. western Mass.*, *Am. Jour. Sci.*, Vol. VIII, p. 39.

1825. **Cacholong.**
Before cited.
S. Robinson: Cat. Am. Min., p. 54.
1825. **Yellow ferruginous quartz.** Dalton.
Crystallized and amorphous. J. Porter.
S. Robinson: Cat. Am. Min., p. 47.
1825. **Jasper, hornstone, agate, quartz crystals, ferruginous quartz.**
Pittsfield. Dalton. New Marlboro.
Massive and crystallized. Very large agates in masses of hornstone and jaspery quartz and jasper; Pittsfield. Ferruginous quartz in yellow crystals; Dalton.
Arenaceous quartz; New Marlboro.
C. A. Lee: Min. Loc., Am. Jour. Sci., Vol. IX, p. 43.
1825. **Blue quartz.** Windsor.
Of good color in amorphous masses. (J. Porter.)
S. Robinson: Cat. Am. Min., p. 77.
1841. **Chalcedony.** Tyringham.
E. Hitchcock: Final Rept., p. 186.
1841. **Mammillary chalcedony.** Tyringham.
Nos. 2328, 2329 in catalogue of State collection.
(Quartz.)
E. Hitchcock: Final Rept., p. 819.
1854. **Mammillary chalcedony.** Tyringham.
Nos. 236, 237.
E. Hitchcock: Cat. Rocks of Mass., 6th Rept. Mass. Bd. Agri., Appendix, p. 54.
1876. **Quartzite, iron flint.** Hinsdale.
C. U. Shepard: Cat. Min. within 50 miles of Amherst, p. 7.
1890. **Quartz.** Hinsdale.
Large geode cavities, with fine slightly smoky crystals, doubly terminated with very short prisms associated with specular iron.
Coll. of E. B. Underhill, Hallock Mills, N. Y. Presented to Amherst College, 1888.
1890. **Quartz.** Becket (east of Shaw Pond).
Blue chalcedony with drusy surfaces, in boulders of pre-Cambrian gneiss.
1895. **Amethyst.** Becket (R. Alderman's).
In contact selvage of pre-Cambrian limestone with actinolite, etc.
1895. **Quartz.** Monterey (Bear Mountain).
Pre-Cambrian. In pale smoke-gray crystals, with etched and rounded faces, associated with fine fibrous actinolite and graphite.
D. Clark collection.
1895. **Quartz.** Tyringham (the Cobble).
In well-terminated crystals in a granite vein.
D. Clark collection.
1895. **Rose quartz.** Otis (roadside near east side of Tyringham).
D. Clark collection.
1895. **Yellow jasper.** Tyringham.
In drift; with surface of blue chalcedony. Also a deep liver-red jasper brecciated with white, from boulder in John Winthrop pasture.
D. Clark collection.

1895. Chalcedony. Tyringham (D. Clark farm, one-fourth mile east of house).

Beautiful great masses of translucent chalcedony; flesh color to amber, with small botryoidal surface of bluish or whitish shade.

D. Clark collection.

1895. Jasper. Monterey (Marshall Bidwell's land, near Lake Garfield).

Jasper of various shades of yellow, often colored black by manganese and coated by fine drusy quartz; also colored black by manganese and running into fine blue shades, often raised above the general surface in matted masses of finely interlaced threads, as if the quartz had coated rootlets. This is the best locality, but the same jasper is found all up and down the Tyringham Valley in the drift—at Fernside, in Otis, in Becket, where a great mass was blasted in the roadside, and near the West Becket post-office. All these jaspers indicate faults.

D. Clark collection.

1895. Brown jasper-agate. Tyringham.

Beautiful botryoidal masses showing white and brown concentric rings from the truncation of the balls.

D. Clark collection.

1895. Black quartz. Tyringham (the Cobble and at the foot of the Hop Brook gorge).

A black quartz vein, the mineral often beautifully iridescent from fissuring.

D. Clark collection.

1895. Cellular quartz. Tyringham.

Boulder. A quartz breccia with the pebbles dissolved out. A fault rock probably brought south from the South Dalton fault.

D. Clark collection.

1895. Fetid quartz (necronite). Tyringham.

Boulder.

D. Clark collection.

1895. Quartz crystals. Tyringham (Fernside).

Fine limpid crystals half an inch long.

1895. Greasy quartz. Lee.

From a boulder on the old turnpike from Lee to South Lee, one-fourth mile south of the covered bridge. A fine greasy quartz, white and deep leek-green.

D. Clark collection.

1895. Quartz pseudomorph after albite and containing salite crystals which are often dissolved or replaced by tremolite. Tyringham (Sodom).

In pre-Cambrian limestone; see page 52 for figures and full description.

1895. Amethyst. Tyringham (near Upper Goose Pond).

Of pale color.

1896. Chalcedony. Otis Center.

Boulder. Very large masses of a white chalcedony, which in cavities is fine botryoidal, drusy, and of faint sky-blue color.

It includes angular fragments of a yellow jasper, showing that it is the filling in of a vein in which the yellow jasper had been a previous filling shattered by a later movement of the vein walls. Both contain fragments of the wernerite, which shows that they are fillings of fissures in the calcite bed on the Otis fault.

1896. Jasper. Hinsdale.

In large masses on west slope of hill 1,720 feet high, 2½ miles north of station. Also on Peru road north of Ashmere Lake, in yellow, red, and white colors. (Doubtless from Cheshire quartzite.)

Collected by B. F. Newell.

RUTILE.**1825. Red oxide of titanium. Pittsfield (southeast part; in green quartz). Dalton (in quartz). New Marlboro.**

C. A. Lee: Min. Loc., Am. Jour. Sci., Vol. IX, p. 42.

1832. Rutile (Peritoneous Erythrone-ore). Windsor.

The locality affording rutile in the greatest quantity in the United States is a very extensive ledge of chlorite slate at Windsor, Mass. The crystals of rutile are here thickly disseminated through narrow veins of feldspar traversing this rock, and also occur in seams in the rock itself.

C. U. Shepard: Treat. Min., Vol. II, Pt. I, p. 169.

1844. Rutile (Peritoneous Erythrone-ore). Windsor.

Fine crystals thickly disseminated through veins of feldspar intersecting chlorite slate.

J. D. Dana: Sys. Min., 2d ed., p. 421.

1852. Rutile. Windsor.

C. U. Shepard: Treat. Min., p. 256.

1868. Rutile. Windsor.

J. D. Dana: Sys. Min., 5th ed., p. 161.

1876. Rutilite. Windsor.

C. U. Shepard: Cat. Min. within 50 miles of Amherst, p. 7.

1881. Rutile. Windsor.

In red-brown deeply striated prisms up to 1½ inches long, closely resembling the Chester County, Pennsylvania, variety. In white albite.

1892. Rutile. Windsor.

J. D. Dana: Sys. Min., 6th ed., p. 235.

1895. Rutile. Tyringham. Dalton (Cottsville quarry).

Boulder in Stockbridge limestone. Dark red-brown striated needles.

SCOLECITE.**1895. Scolecite. Tyringham (Hop Brook gorge).**

Radiated blades on orthoclase. In masses of radiated tufts and globules graduating upward into fine globes of 1 inch in diameter of finest fibrous character, also in thick masses so finely fibrous and altered to kaolin that it has a massive porcelaneous look and botryoidal surface, also a soft, drusy surface growth forming great masses of balls an inch across. It also occurs encrusting biotite and pyroxene, and in a later generation with other zeolites. See p. 55.

D. Clark collection.

1895. Scolecite pseudomorph after wernerite. Tyringham (Hop Brook).

(See under wernerite.)

D. Clark collection.

SERPENTINE.

1823. **Serpentine.** Windsor (northwest part).

C. Dewey: Geol. western Mass., Am. Jour. Sci., Vol. VIII, p. 50.

1824. **Serpentine.** Windsor.

C. Dewey: Hist. Berkshire County, p. 191.

- 1824. **Vert antique?** Becket.

A magnesian mineral found in a bed in gneiss on the river in Becket, colored green by serpentine. It may, as Dr. Emmons supposes, be a serpentine marble. It is a tough mineral and takes a fine polish. The quantity of serpentine is sometimes small and the color yellowish white.

C. Dewey: Geol. Berkshire, Am. Jour. Sci., Vol. VIII, p. 58.

(This is the Coles Brook limestone with altered chondrodrite.)

1825. **Vert antique.**

The above localities in Windsor and Becket cited.

S. Robinson: Cat. Am. Min., p. 77.

1825. **Serpentine.** Dalton (east part of town).

Containing asbestos.

C. A. Lee: Min. Loc., Am. Jour. Sci., Vol. IX, p. 43.

1841. **Serpentine.** Windsor (northeast and northwest parts). Cheshire (south of M. House's, a little east of the four corners).

Windsor, northeast part; serpentine with chondrodite. Cheshire; hard serpentine in gneiss.

Catalogue of State collection.

E. Hitchcock: Final Rept., pp. 616, 877, 878.

SPINEL.

1892. **Spinel.** Norfolk, Connecticut.

Spinel is absent in the pre-Cambrian limestones of the Sandisfield and Becket quadrangles, and first appears south of the border of the map in Norfolk in the same limestone.

STAUBOLITE.

1822. **Staurolite.** Pittsfield.

In small, light-brown crystals, either single or crossing each other at right angles.

It is associated with garnets and sulphuret of iron (Hall).

P. Cleaveland: Treat. Min., Vol. II, p. 776.

1823. **Staurolite.** Hinsdale.

"In vast quantities in mica-schist." Am. Jour. Sci., Vol. VI, p. 219.

S. Robinson: Cat. Am. Min., p. 53. This is a citation from Hitchcock's Geology of the Connecticut, and refers to Hinsdale, New Hampshire. Hitchcock is giving the list of towns up the Connecticut and crosses the State line without indicating it.

1824. **Staurolite.** Sheffield.

In small area of mica-schist.

C. Dewey: Am. Jour. Sci., Vol. VIII, p. 7.

1885. **Staurolite.**

J. D. Dana: Am. Jour. Sci., 3d ed., Vol. XXIX, p. 214.

STILBITE.

1895. **Sphaerostilbite.** Tyringham (Hop Brook).

Pre-Cambrian. In balls with faceted faces, radiated within with pearly luster. Fine groups coating biotite; also in sheaves and in segments of wheels. One beautiful cylindrical mass, 7 inches high, $4\frac{1}{4}$ inches in diameter, covered with the warty protuberances made of the fine spheres, was sent to the exposition at Chicago. One mass more than a foot across was found. There is also a second growth of small, single crystals of stilbite. It occurs also in separate projecting and interlaced thick blades $\propto P \propto (010)$, $\propto P \propto (100)$, $OP (001)$. Color, opaque-white, often smoky exteriorly. Other crystals appear with tapering ends from the development of $P (111)$. Other specimens are small, limpid, single crystals $\propto P \propto (100)$, $\propto P \propto (010)$, $OP (001)$.

The zeolites were found in a rotten vein in the coarse pyroxene rock with big crystals of dark brownish black biotite changed to jefferisite; well-formed crystals $1\frac{1}{4}$ inches to 5 inches across, some often fused together by sphaerostilbite and deeply warped.

D. Clark collection.

SULPHUR.

1824. **Sulphur.** Tyringham.

In mica-slate.

C. Dewey: Geol. western Mass., Am. Jour. Sci., Vol. VIII, p. 54.

1824. **Sulphur.** Hinsdale.

In cavities of a mica-slate rock consisting chiefly of quartz. It is a brown powder, from its mixture probably with oxide of iron.

C. Dewey: Geol. Berkshire, Am. Jour. Sci., Vol. VIII, p. 33.

1825. **Sulphur.** Localities in Tyringham and Hinsdale cited above.

S. Robinson: Cat. Am. Min., pp. 54, 73.

I have not found sulphur in the cavities of the Hinsdale gneisses, which are, however, often filled with a yellow pulverulent limonite.

TALC.

1823. **Steatite (potstone).** Windsor.

Very fine; formerly wrought into inkstands, which are still made by Shakers.

C. Dewey: Geol. western Mass., Am. Jour. Sci., Vol. VIII, p. 51.

1824. **Talc.** Windsor.

C. Dewey: Hist. Berkshire County, p. 191.

1824. **Steatite.** Windsor.

C. Dewey: Geol. Berkshire, Am. Jour. Sci., Vol. VIII, p. 51.

1825. **Steatite.**

Cited above. Also talc. (H. M. Wells.)

S. Robinson: Cat. Am. Min., p. 77.

1825. **Talc.** Pittsfield.

Of different colors.

C. A. Lee: Min. Loc., Am. Jour. Sci., Vol. IX, p. 43.

1841. **Steatite.** Hinsdale.

E. Hitchcock: Final Rept., p. 156.

1841. **Steatite.** Hinsdale.

In gneiss.

E. Hitchcock: Final Rept., p. 610.

1892. **Talc.** Hinsdale.

The great beds of talc connected with the Hinsdale limestone are described on pages 28-32. The largest beds are at the quarry near Wakonah Falls, the stratum being 30 feet thick, where the brook from Ashmere reservoir crosses River Bend Farm below the mill pond.

TITANITE.

1824. **Red oxide of titanium.** Pittsfield.

In small prisms in quartz associated with dolomite; rare.
C. Dewey: Geol. Berkshire, Am. Jour. Sci., Vol. VIII, p. 58.

1841. **Sphene.** Lee (east part of town). Tyringham.

Lee; in augitic gneiss; finest in New England; No. 1091, Cat. State Coll., p. 637. In talcose limestone, No. 1981, Cat. State Coll., p. 810.
Tyringham; with hornblende, No. 2301, Cat. State Coll., p. 818.
E. Hitchcock: Final Rept. Geol. of Mass.

1844. **Sphene** (*Rutilus obliquus*). Lee (eastern part).

Very good specimens in gneiss.
J. D. Dana: Sys. Min., 2d ed., p. 422.

1854. **Sphene.** Becket.

In talcose limestone (probably Coles Brook bed).
E. Hitchcock: No. 193, Cat. Mass. Coll., Agri. Rept., p. 35.

1858. **Sphene.** Tyringham.

With hornblende; No. 210.
E. Hitchcock: Cat. Mass. Rocks in 6th Ann. Rept. Mass. Bd. Agri.

1868. **Sphene.**

J. D. Dana: Sys. Min., 5th ed., p. 386.

1872. **Sphene.**

J. D. Dana: Sys. Min., 6th ed., p. 715.
E. Hitchcock: Final Rept. Geol. of Mass.

1895. **Titanite.** Sandisfield. Becket. Coles Brook.

Sandisfield; in drift on Birch Hill, with hornblende and wernerite.
Becket; 100 rods east of R. Alderman's house.
Crystals a half inch long.
Coles Brook; in Hinsdale limestone.

1895. **Titanite.** Tyringham (Sodom, Hop Brook gorge).

In pre-Cambrian limestone. Beautiful flat transparent chestnut-brown crystals, often an inch long. Some are rich red-brown at one end and grade to clove-brown or dusty-white at the other. There are also most beautiful limpid hyacinth-red bladed crystals in calcite. In Sodom chestnut-brown crystals occur in pink calcite with radiating black hornblende. They show the faces $OP(001)$, $P(111)$, $\infty P\infty(100)$, $\infty P(110)$, and multiple twinning according to the third law (Dana) approximately parallel to 221.
D. Clark collection.

1895. **Titanite.** New Marlboro (road to Southfield).

Deep cutting in rusty rock by roadside. Pre-Cambrian. Large pale-brown wedge-shaped crystals.
D. Clark collection.

1895. **Titanite.** East Lee (east of the Gousset road).

Boulder of pre-Cambrian Hinsdale limestone.
The crystals are half an inch long and of pale Isabella yellow. Forms: $OP(001)$, $\infty P\infty(100)$, $\infty P(110)$, $P(111)$.
D. Clark collection.

1895. **Titanite.** Becket (near West Becket post-office).

A large mass was blasted out in improving the road. The mineral occurs in a white, granular feldspar rock (pre-Cambrian), with green actinolite, and is probably from an altered form of the Hinsdale limestone. It is in very abundant crystals of rich chestnut color, often an inch long, and shows the forms OP (001), P (111), ∞ P (110).

D. Clark collection.

1895. **Titanite.** Otis (Hop Brook gorge).

From the upper bed of pre-Cambrian limestone. Flat-bladed chestnut-brown crystals an inch long.

D. Clark collection.

TOURMALINE.

1821. **Schorl.** Dalton. Pittsfield (southeast part of the town).

In mica-slate.

C. A. Lee: Min. Loc., Am. Jour. Sci., Vol. IX, p. 42.

1822. **Yellow tourmaline.** Dalton (near the Housatonic).

In groups of straw-yellow crystals from an inch to 2 inches long, sometimes with terminations in granular limestone (M'Euen).

P. Cleaveland: Min., p. 321.

This interesting occurrence I have not been able to verify. It may be tremolite in the Stockbridge limestone, but from the great abundance of minute tourmaline in the subjacent Cheshire quartzite the occurrence of tourmaline in the limestone is not improbable.

1824. **Black tourmaline.** Washington.

J. Porter: Min. Loc., Am. Jour. Sci., Vol. VII, p. 252.

I have not found this mineral in Washington.

1825. **Yellow tourmaline.** Dalton (near the Housatonic).

In groups of straw-colored crystals in granular limestone.

S. Robinson: Cat. Am. Min., p. 46.

1895. **Tourmaline.** Sandisfield (in field near Mr. George Blake's house).

Black crystals 1 inch across and 3 to 5 inches long, in a small pegmatite vein, much jointed, faulted, and recemented into beautiful series of echeloned disks.

1895. **Tourmaline.** Tyringham (the Cobble).

In well-terminated black crystals in a granite dike.

D. Clark collection.

1895. **Tourmaline.** Sandisfield (near town hall).

Black crystals 1½ inches across, much jointed, and recemented with quartz.

D. Clark collection.

WERNERITE.

1841. **Scapolite.** Tyringham. Lee.

Tyringham; crystallized hornblende and scapolite; No. 2300, State collection.

Lee; augite with scapolite; No. 1092, State collection.

E. Hitchcock: Final Rept. Geol. of Mass., p. 818.

1844. **Scapolite.** (*Scapolus pyramidalis.*) Tyringham.J. D. Dana: *Sys. Min.*, 2d ed., p. 539.1858. **Scapolite.** Tyringham.

With hornblende.

E. Hitchcock: No. 218, *Cat. Rocks of Mass.*, 6th Ann. Rept. Mass. Bd. Agri.1868. **Scapolite.**J. D. Dana: *Sys. Min.*, 5th ed., p. 770.1892. **Scapolite.**

Idem, 6th ed., p. 1059.

1895. **Wernerite.** Tyringham (Hop Brook gorge, Sodom).

Pre-Cambrian. Pure white prisms 2 inches long and 1 inch square. Other crystals in almost acicular square prisms; crystals generally bent or broken by later growth of hornblende.

D. Clark collection.

1895. **Wernerite.** Lee (Upper Goose Pond, near Elwells Rocks).

Peculiar forms; deep topaz to flesh-colored; glassy and highly lustrous on crystal faces; transparent, and a true gem form. Some crystals broken. The crystals are black at base and change up through brown and wine-yellow to nearly colorless. Inset crystals raised from the polished faces. The ∞ P ∞ (101) cleavage is perfect; crystals are half an inch wide and 1 inch long, with the form ∞ P ∞ (101), P (111).

Masses 2 inches square show deep flesh-color; more fibrous cleavage, like ordinary scapolite; growing paler by alteration. Blades of deep-green actinolite and pyroxene prisms are grown through the mass.

Also large masses of coarse granular texture composed of imperfect stout crystals 1 inch across, bluish gray shading to white at border, and very fresh, greasy luster, with biotite.

D. Clark collection.

1895. **Wernerite changing into scolecite.** Tyringham (Hop Brook gorge).

Large imperfect square prisms, with greasy bluish luster, and masses of a colorless wernerite granular rock, full of small phlogopites and actinolite blades, are changed to a mass of radiated fine fibrous balls of scolecite, opaque white, at the surface forming delicate botryoidal surfaces of the fine free needles. In cross sections the balls are concentrically banded, the lower half opaque-white, the upper translucent. This wernerite is found in masses of tons in size along the brook gorge, white and pale gray, with crystals growing from the surface. Other crystals are small square prisms one-half inch long, one-fourth inch wide, often bent; snow-white, with satiny luster, apparently changed to scolecite in needles parallel to OP (001). Other specimens are also coated with the radiated balls of scolecite as above. One piece bristles with white needles of wernerite one-half millimeter across, many of which are deep square hollows, leaving only shells, and many are inclosed in deep-green pyroxene and remain hollow.

D. Clark collection.

1895. **Wernerite.** Tyringham (Hop Brook).

A large impure crystal, full of calcite and phlogopite, was examined in thin section under the microscope. The crystal is full of minute, long, square prisms, whose cleavage, high relief, and oblique extinction show them to be white pyroxene. The wernerite is brown, shaded in irregular patches, which are white by reflected light. This is caused by the fibrous

decomposition product common in wernerite, which is optically positive and has very weak double refraction ($V = .008$), agreeing exactly with scolecite. A twinning suture runs parallel with OP (001), and the optical axis makes an angle of 16° with this on either side.

1895. **Wernerite.** Sandisfield (Beech Plain).

In drift, with hornblende and titanite.

1895. **Wernerite.** Otis (Otis Center).

The coarse limestone at Otis Center contains wernerite in groups of stout, white, interlaced crystals and purple glassy masses. It occurs in the brook bed near the mill and just west of the village street.

ZOISITE.

1841. **Zoisite.** Hinsdale.

In mica-schist.

E. Hitchcock: Final Rept., 606.

(I have never seen zoisite from Hinsdale. It may be the same mineral cited herein as fibrolite.)

1844. **Zoisite.** (*Carbunculus rhomboideus*.) Hinsdale. Windsor.

J. D. Dana: Sys. Min., 2d ed., p. 300.

1868. **Zoisite.**

Idem, 5th ed., p. 292.

1892. **Zoisite.**

Idem, 6th ed., p. 514.

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1814. MEADE (W.). Mineralogical notice concerning elastic marble from Massachusetts. A. Bruce, Am. Min. Jour., Vol. I, pp. 93, 267.
- On taking up one of these slabs it was found to be so completely elastic that the writer feared it would fall in pieces before he could replace it.
1816. CLEVELAND (Parker). Elementary treatise on mineralogy and geology, with colored geological map of the United States; 668 pages.
- The map was taken from Maclure. Berkshire County is colored as "Primitive."
1818. EATON (Amos). An index to the geology of the northern States, with a transverse section from the Catskill Mountains to the Atlantic, prepared for the geological classes at Williams College, Northampton, Belchertown, Leicester, and Worcester (Massachusetts).
- The section gives, although crudely, the Hinsdale anticline, but makes its core granite instead of gneiss, and identical with the much later granite of Chesterfield. On this granite rest the "granular limestone" and quartz. This is the Hinsdale limestone, and it is clearly separated from the newer "metalliferous limestone" to the west, the latter being the Stockbridge limestone (p. 84).
- Next above this is the gneiss, which "sinks laterally under the mica-schist to the west, and probably does not rise again until it reaches the continent of Asia." Above this is the mica-slate, "the calcareous and granular quartz," the "soapstone rocks," including the hydromica-schists, as well as the steatite and serpentine, and lastly the "syenite." By this is meant the Chester and Hawley amphibolites, and he notes the spotted or "porphyritic" varieties in Hawley. This bed is said to cap the series east of Dalton, and "therefore all the tract is 'Primitive.'"
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1820. EATON (Amos). An index [etc.]; 2d edition.
- "Written over anew."
1820. ——— Localities of minerals, from the minutes of the Troy Lyceum. Am. Jour. Sci., Vol. II, p. 238.

1821. DEWEY (C.). Fetid dolomite found in Lee; found by analysis to be magnesia. *Am. Jour. Sci.*, Vol. III, p. 239.
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- 1823-6. *Boston Journal of Philosophy and the Arts*. J. W. Webster, editor. 3 vols.
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1824. A history of the county of Berkshire, Mass. By gentlemen of the county, clergymen, and laymen. Colored geological map.
Geology by Prof. Chester Dewey. The central gneiss mass, with soap-stone and serpentine, is mentioned. The quartzite and the limestone are said to extend south in two bands; the western, from Adams to Cheshire, is the Stockbridge limestone; that from Windsor to New Marlboro is pre-Cambrian.
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1824. DEWEY (Chester). A sketch of the geology and mineralogy of the western part of Massachusetts, and a small part of adjoining States. *Am. Jour. Sci.*, Vol. VIII, pp. 1-60. Geological map.
The first connected account of the geology of Berkshire County. All the upland country mapped in this study is assigned to mica-slate except a band of gneiss along the Peru line and a broad band of primitive limestone which runs down across Hinsdale and Washington and is given the same color as the valley limestone. The quartzite is the only other rock distinguished upon the map.
1824. ———. Additional remarks on foregoing. *Am. Jour. Sci.*, Vol. III p. 240.
1825. LEE (Charles A.). Notice of minerals in Pittsfield and Dalton. *Am. Jour. Sci.*, Vol. IX, pp. 42, 43.
1825. ROBINSON (Samuel). A catalogue of American minerals, with their localities. Boston.
Quotes minerals from Becket, Dalton, Hinsdale, Lee, Lenox, New Marlboro, Pittsfield, and Windsor.
1830. EATON (Amos). Geological text-book. Albany.
Southeastern Berkshire is mapped as follows: limestone from the west up to the Housatonic; quartzite east of this to Franklin and Hampshire counties; in the southeastern corner is primitive, interrupted by a band of limestone entering from Litchfield County.

1830. A history of the county of Berkshire, Massachusetts, in two parts; the first being a general view of the whole county; the second an account of the several towns, by gentlemen of the county, clergymen, and laymen. Geographical and geological map.

Geological part by Prof. Chester Dewey.

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Area made hypozoic and metamorphic.

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1858. HITCHCOCK (E.). Geological map of Berkshire County.
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1859. ——— Agricultural museum catalogue of collection of rocks, minerals, and fossils in the State cabinet, obtained during the geological surveys of the State by Dr. Edward Hitchcock, with later additions. Appendix 6th Ann. Rept. of Board of Agriculture. Boston: State printer.
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1872. DANA (J. D.). Green Mountain geology. *Am. Jour. Sci.*, 3d series, Vol. III, pp. 179, 250.
On the quartzite.

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1873. HITCHCOCK (C. H.) and BLAKE (W. P.). Geological map of the United States.

The hill country on the east is assigned to the Eozoic; the western valley to the Silurian.

1875. BRADLEY (F. H.). A geological chart of the United States.

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1876. SHEPARD (C. U.). Catalogue of minerals found within 75 miles of Amherst College. Privately printed May 20, 1876.

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1876. CROSBY (W. O.). Report on the geological map of Massachusetts, prepared for the Centennial Exposition at Philadelphia. Boston. 52 pp.

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1877. HITCHCOCK (C. H.). Geology of New Hampshire. 3 vols. Atlas in folio.

Vol. II, p. 8, Pl. I, assigns the valley to the Silurian and Cambrian; Bear Mountain and the area south across Monterey, New Marlboro, and Norfolk to the Laurentian; and the broad area of the Cambrian gneisses to the east of these subdivisions to the "Atlantic"—a subdivision of the Archean between the Laurentian and the Huronian.

1879. ——— Macfarlane's railroad guide.

This gives Professor Hitchcock's views as to the age of the rocks in the area along the Housatonic and Boston and Albany railroads. The Hinsdale pre-Cambrian is called Green Mountain gneiss; the hydromica-schist of Middlefield, Huronian.

1880. DANA (J. D.). Note on the age of the Green Mountains. *Am. Jour. Sci.*, Vol. XIX, p. 191.

Only general considerations on this special region.

1881. HITCHCOCK (C. H.). Geological map of the United States and Territories. Julius Bien. Scale, 20 miles to an inch.

The gneisses are assigned to: "Gneisses of the Atlantic Slope, including Montalban," and "Metamorphic Paleozoic;" the valley rocks, to Lower or Cambro-Silurian (Lorraine to Calciferous).

1882. DANA (J. D.). Geological age of the Taconic system. *Jour. Geol. Soc.*, Vol. XXXVIII, p. 397.

Refutation of Hunt's idea of the pre-Cambrian age of the Taconic. The map gives the slates and limestones, leaves the highlands uncolored, and writes over Bear Mountain, "Here some Archean!"

- 1883-1885. KUNZ (George F.). Precious stones; from Mineral Resources of the United States, U. S. Geol. Survey.
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1884. HITCHCOCK (C. H.). Geological map of the United States, in The National Atlas. Grey, Philadelphia.
1884. DANA (J. D.). On the decay of quartzite and the formation of sand, kaolin, and crystalline quartz. Am. Jour. Sci., Vol. XXVIII, p. 448.
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1884. HAWES (G. W.), KELLEY (C.), MERRILL (G. P.), and SHALER (N. S.). Report on the building stones of the United States. Tenth Census, Vol. X.
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1885. DANA (J. D.). Decay of quartzite: Pseudo-breccia. Am. Jour. Sci., Vol. XXIX, p. 57.
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1885. (1883-84.) HUNT (T. S.). The Taconic question in geology. The "Taconian" is a late pre-Cambrian formation. Trans. Can. Roy. Soc., Vol. I, Pt. 4, p. 227; Vol. II, p. 125.
1885. DANA (J. D.). On Taconic rocks and stratigraphy, with a geological map of the Taconic region. Am. Jour. Sci., Vol. XXIX, pp. 205, 437.

1886. Topographical map of the State of Massachusetts. Executed by the United States Geological Survey, at the joint expense of the State and the Survey.

Scale 1: 62,500; 20-foot contours in brown; water in blue; roads in black.

1887. DANA (J. D.). On Taconic rocks and stratigraphy, with a geological map of the Taconic region. *Am. Jour. Sci.*, Vol. XXXIII, p. 270.

Also published separately, with 1885 part.

1888. Geology of Berkshire County. Child's Berkshire County Gazetteer, pp. 24-26.

Inadequate and worthless.

1888. WALCOTT (C. D.). The Taconic system of Emmons, with map covering western border of the area. *Am. Jour. Sci.*, Vol. XXXV, pp. 229, 307, 394.

1889. MERRILL (George P.). Handbook and catalogue of building and ornamental stones in the United States National Museum. Rept. Smith. Inst., 1885-86, p. 277, Pls. I-IX.

1890. DANA (J. D.). Archæan axes of eastern North America. *Am. Jour. Sci.*, Vol. XXXIX, p. 378.

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R. H. Cornish writes of a limestone ledge with spinel and chondrodite on land of Mr. Ralph Cressey, near a spring southeast of his house.

1890. CROSBY (W. O.). Macfarlane's geological railway guide, 2d edition. Gives character of rocks along Boston and Albany Railroad.

1890. EMERSON (B. K.). Porphyritic and gneissoid granites in Massachusetts. *Bull. Geol. Soc. Am.*, Vol. I, p. 559.

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1891. WALCOTT (C. D.). Correlation papers: Cambrian. *Bull. U. S. Geol. Survey*, No. 81.

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1892. HOBBS (William H.). Intergrowths of hornblende with augite in crystalline rocks. *Science*, Vol. XX, p. 354.

Augite surrounding hornblende, from the Cleveland mine.

1892. ———. Notes on some pseudomorphs from the Taconic region. *Am. Geologist*, Vol. X, p. 47.

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1894. PUMPELLE (Raphael), WOLFF (J. E.), and DALE (T. Nelson). Geology of the Green Mountains in Massachusetts. Mon. U. S. Geol. Survey, Vol. XXIII.

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1895. DANA (J. D.). Manual of geology, 4th edition.

1895. SHALEE (N. S.). The geology of the road-building stones of Massachusetts. Sixteenth Ann. Rept. U. S. Geol. Survey, Vol. II, p. 277.

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